CE 3401: Environmental Engineering 1

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COURSE INFORMATION
Environmental Engineering I
MD Ehasan Kabir

No.	Course Learning Outcomes
CLO1	Understand the fundamental concepts and principles of environmental engineering.
CLO2	Identify and analyze environmental problems and their potential solutions.
CLO3	Apply engineering principles and techniques to the design and implementation of environmental control systems.
CLO4	Evaluate the environmental impact of engineering projects and develop mitigation strategies.
CLO5	Understand the ethical and professional responsibilities of environmental engineers.

Week	Topic	Teaching Learning Strategy	Assessment Strategy	Corresponding CLOs
01	Introduction to Environmental Engineering	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO1
02	lowcost water supply	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4

03	surface water collection	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
04	pumps and pumping machinery	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
05	pumps and pumping equations	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
06	Water Distribution (Pipe network, Storage reservoir)	Lecture, Oral presentation	Class Test	CLO2, CLO3, CLO4
07	Water conveyance (Corrosive, Scale forming water)	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
08	Water conveyance (Corrosive, Scale forming water)	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
09	Well-Design	Lecture, Oral presentation	Class Test	CLO2, CLO3, CLO4
10	Sedimentation	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
11	Adsorption	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
12	Coagulation	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
13	Filtration	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
14	Fluoride Removal	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2,

				CLO3, CLO4
15	Gas transfer	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
16	Nitrate Removal	Lecture, Oral presentation	Daily Quiz, Sudden test	CLO2, CLO3, CLO4
17	Reverse Osmosis_Electrodialysis	Lecture, Oral presentation	Class Test	CLO2, CLO3, CLO4

Week-(01)

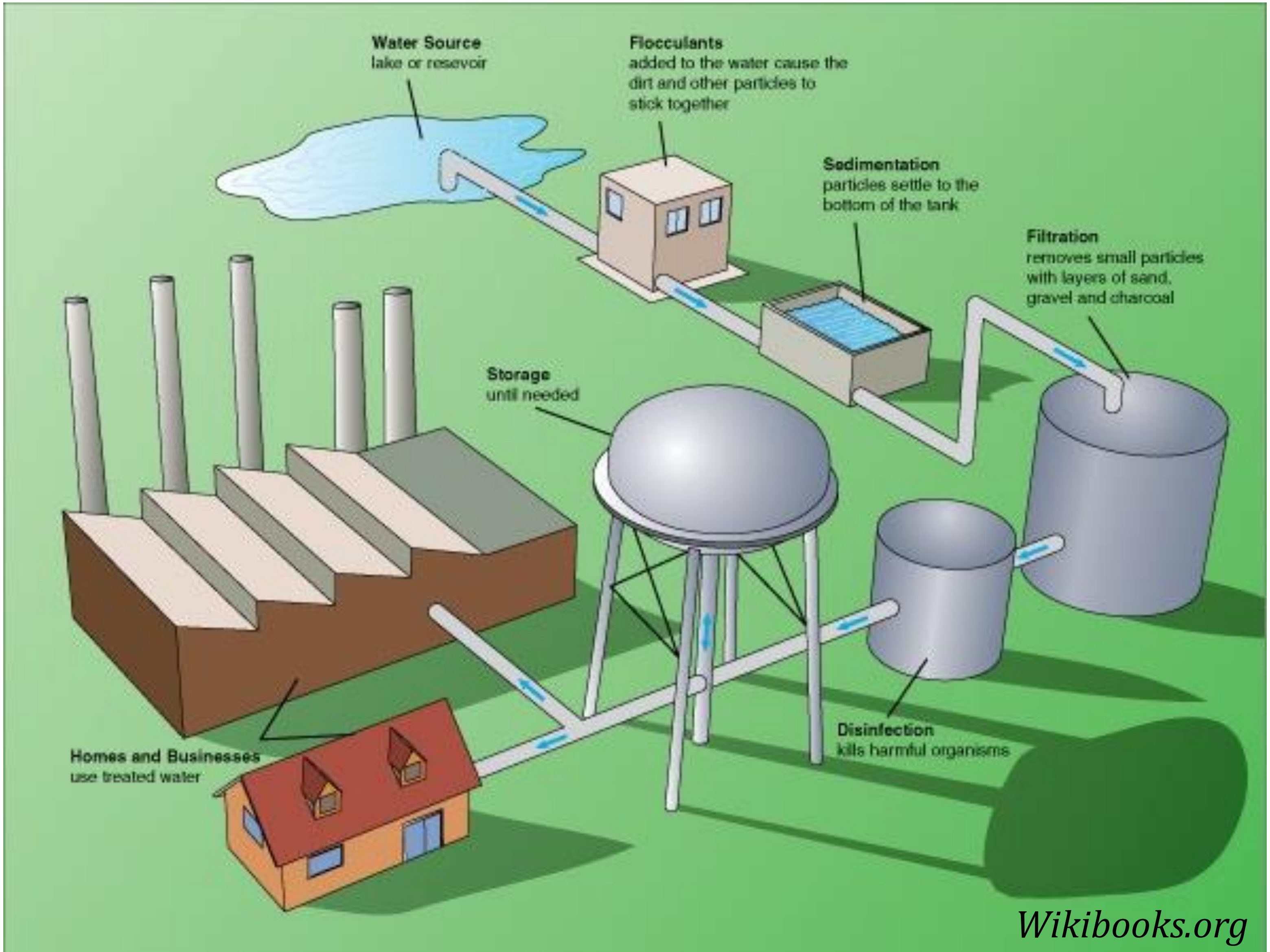
MD Ehasan Kabir

Environmental Engineering: Definition

"Environmental Engineering is manifest by sound engineering thought and practice in the solution of problems of environmental sanitation, notably in the provision of safe, palatable, and ample public water supplies; the proper disposal of or recycle of wastewater and solid wastes; the adequate drainage of urban and rural areas for proper sanitation; and the control of water, soil and atmospheric pollution, and the social and environmental impact of these solutions. Furthermore it is concerned with engineering problems in the field of public health, such as control of arthropod-borne diseases, the elimination of industrial health hazards, and the provision of adequate sanitation in urban, rural and recreational areas, and the effect of technological advances in the environment….."

Environmental Engineering Division, ASCE.

CE 331: Provision for Safe Water Supply



CE 331 Topics

- Water sources and availability
- Water collection systems, well hydraulics
- Water treatment systems (theory, practice and design)
- Pumps and pumping machinery
- Water distribution systems, pipe hydraulics
- Maintenance of water supply systems

CE 331 References

- **Water Supply and Sanitation**
  M. Feroze Ahmed & Md. Mujibur Rahman
  (ITN-Bangladesh)
- **Water and Environmental Engineering**
  Md. Habibur Rahman & Abdullah-Al-Muyeed
  (ITN-Bangladesh)
- **Water Supply Engineering**
  M. A. Aziz

Water Sources: Global View

Item	Area (10^6 km^2)	Volume (km^3)	Total water %	Fresh water %	Rates of exchange
Oceans	36.31	1 338 000 000	96.5		3000–30 000 yrs
Groundwater					
Fresh	134.8	10 530 000	0.76	30.1	Days to 1000 yr
Saline	134.8	12 870 000	0.93		
Soil moisture	82.0	16 500	0.001 2	0.05	2–52 weeks
Polar ice	16.0	24 023 500	1.7	68.6	1–16 000 years
Other ice and snow	0.3	340 600	0.025	1.0	
Lakes					
Fresh	1.2	91 000	0.007	0.26	1–100 years
Saline	0.8	85 400	0.006		10–1000 years
Marshes	2.7	11 470	0.000 8	0.03	
Rivers	148.8	2 120	0.000 2	0.006	10–30 days
Biological water	510.0	1 120	0.000 1	0.003	7 days
Atmospheric water	510.0	12 900	0.001	0.04	8–10 days
Total water	510.0	1 385 984 610	100.0		2800 years
Fresh water	148.8	35 029 210	2.5	100.0	

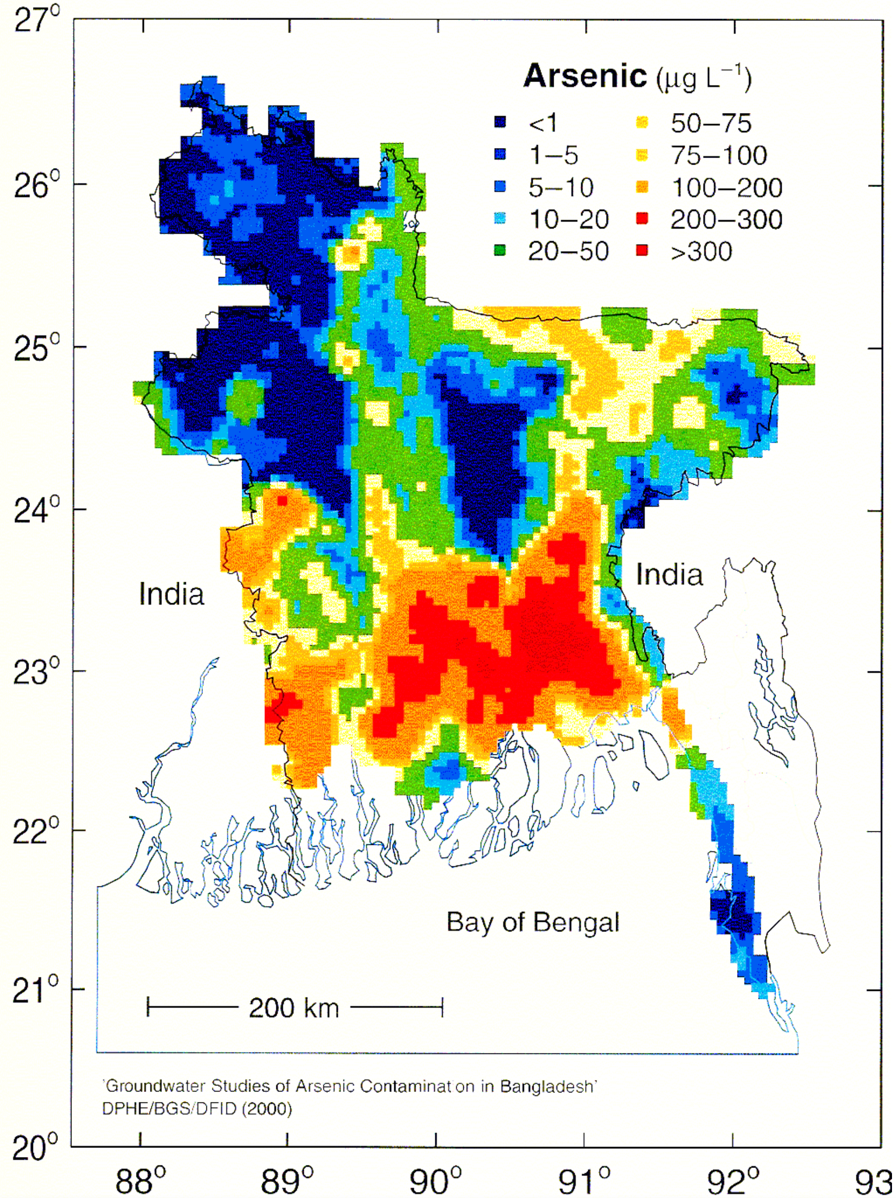
Adapted from UNESCO, 1978

Freshwater amounts to only <3% of the global water.

Water Sources and Characteristics

Surface water (rivers, ponds and lakes)	Exposed to atmosphere, receives pollution from domestic, industrial and agricultural sources, Microbial pollution Quality of water of rivers more variable and less satisfactory than lakes and ponds
Groundwater	Generally free from suspended impurities, microbes due to long and slow travel thorough soil, rich in minerals
Rainwater	Free from all impurities except those picked up from the air but can be contaminated from the collection catchment (roof). Rainwater is aggressive due to low mineral content.

Problems in GW Development in Bangladesh

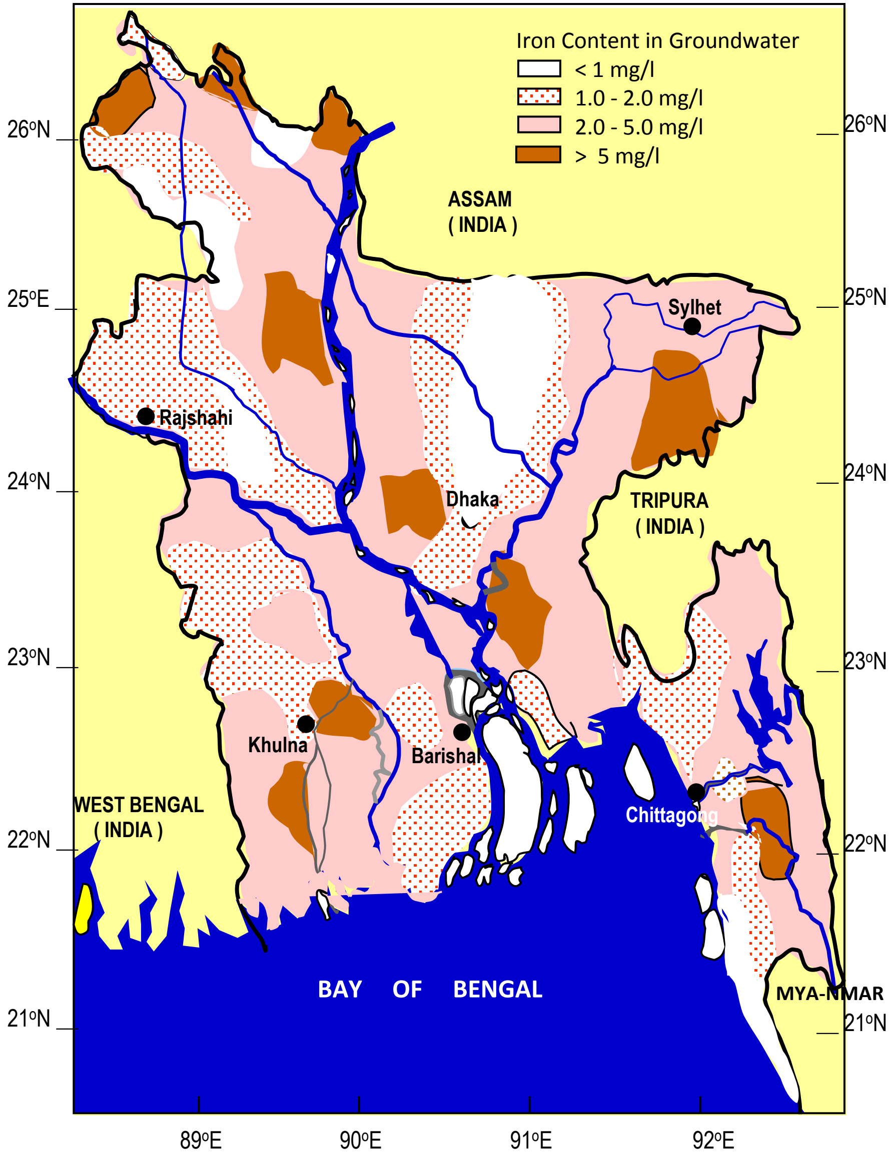


Groundwater is the main source (90%) of drinking water supply in Bangladesh.

Arsenic contamination

- ❑ First detected in 1993 in Chapai Nawabgonj
- ❑ One in every three shallow tubewells (STW) producing water in excess of acceptable limits (46% STW > 0.01 mg/L, 27% STW>0.05 mg/L)

Problems in GW Development in Bangladesh



Excess Dissolved Iron

❑ 67% Area served by STW produces water with Iron exceeding 0.02 mg/L (WHO acceptable limit is 0.01 mg/L)

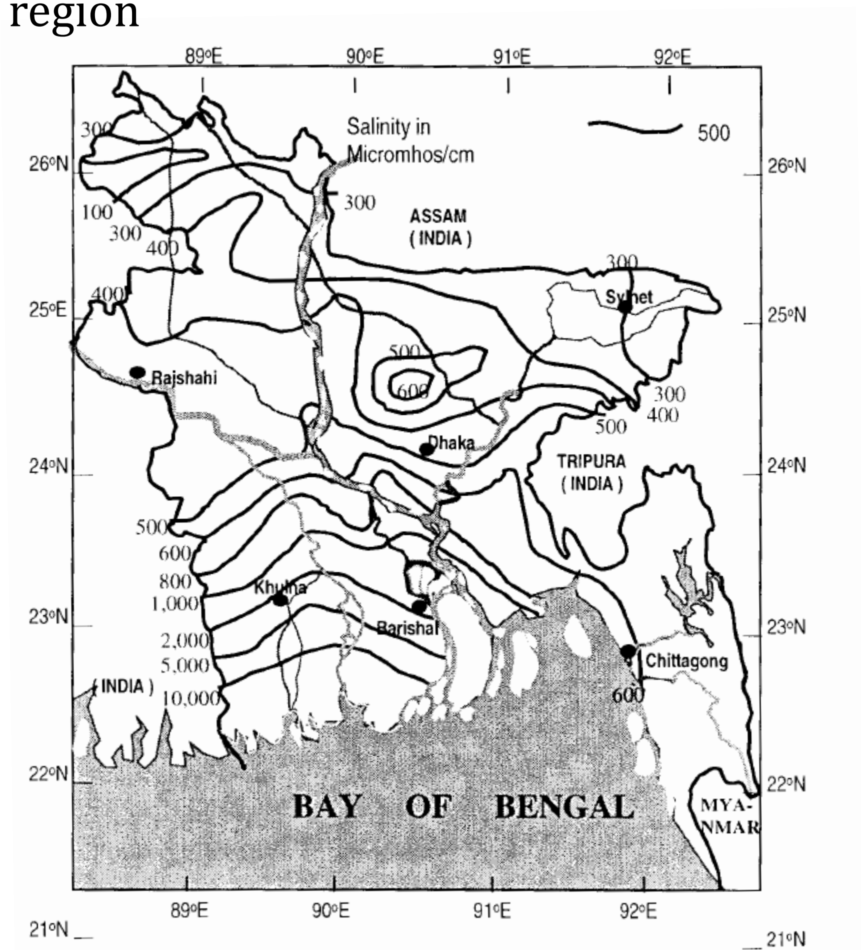
❑ Iron content in Deep tube well water is comparatively lower.

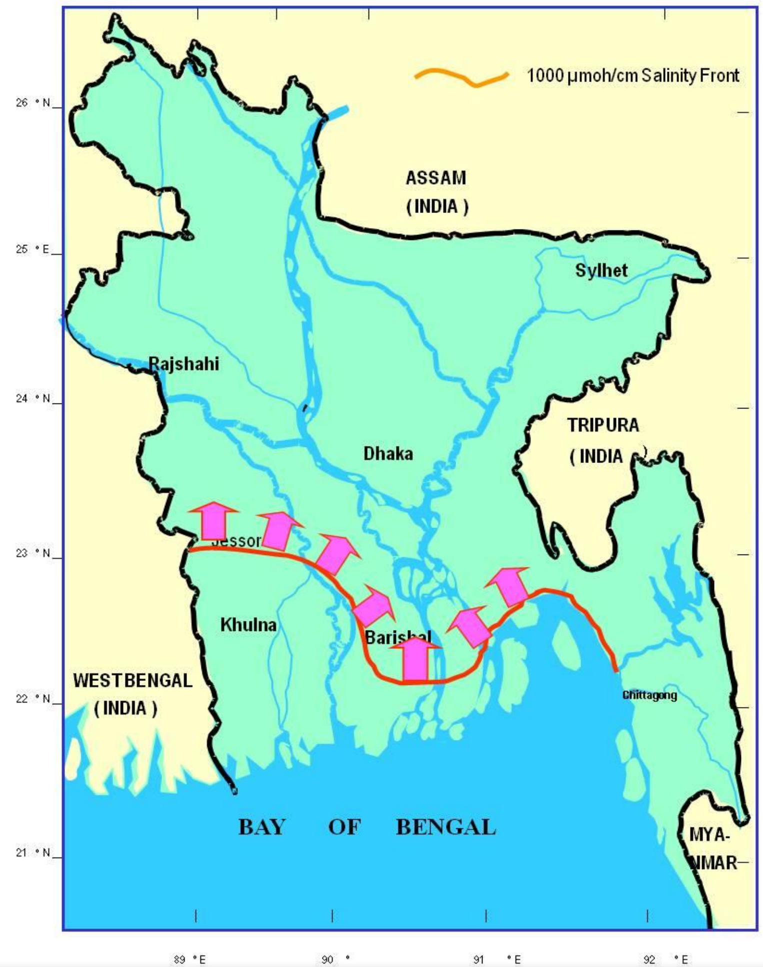
Problems in GW Development in Bangladesh

Salinity in coastal areas

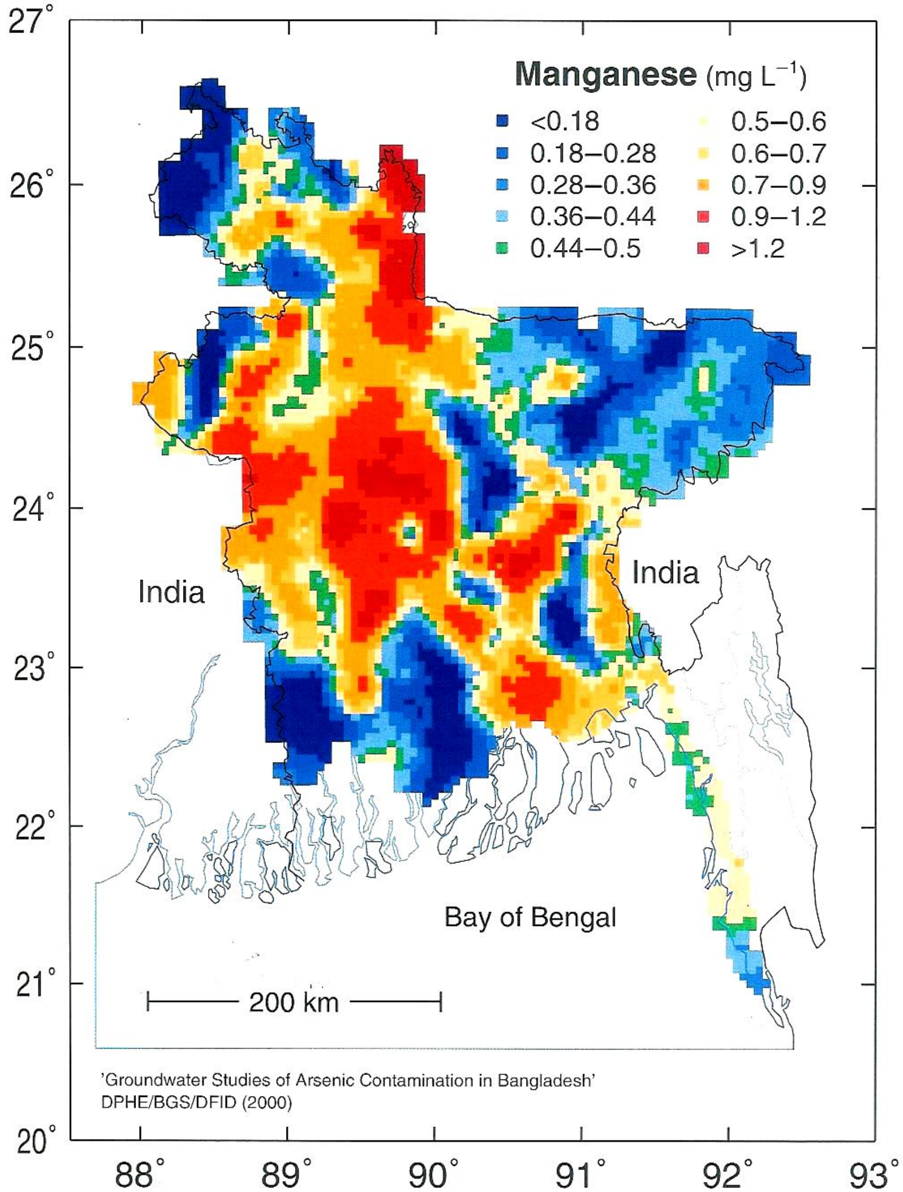
- ❑ Acceptable quality of groundwater is not available in most parts of the coastal region

Salinity front will move upward due to lower upstream flow in the dry season and sea level rise.





Problems in GW Development in Bangladesh



- ❑Manganese in groundwater is very high.
- ❑About 35% of the drinking water samples had manganese in excess of WHO health-based Guideline Value of 0.4 ppm;
- ❑Bangladesh Standard for manganese in drinking water is 0.1 ppm and few samples meet this requirement

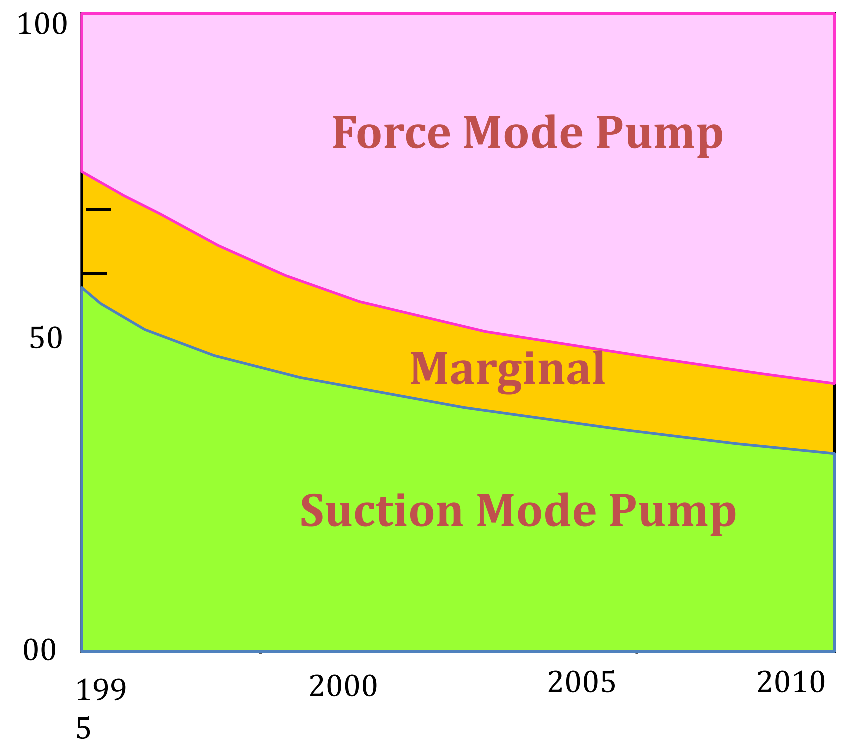
Problems in GW Development in Bangladesh

Lowering of groundwater level

- ❑ Over-exploitation of groundwater for irrigation purposes
- ❑ A gradually decreasing suction mode pumps being used over time in low water table areas is predicted.

Rock/stony layers in hilly areas

- ❑ Drilling of tubewells by conventional methods become difficult
- ❑ Mechanical drilling rigs are required which increases the cost of installation.



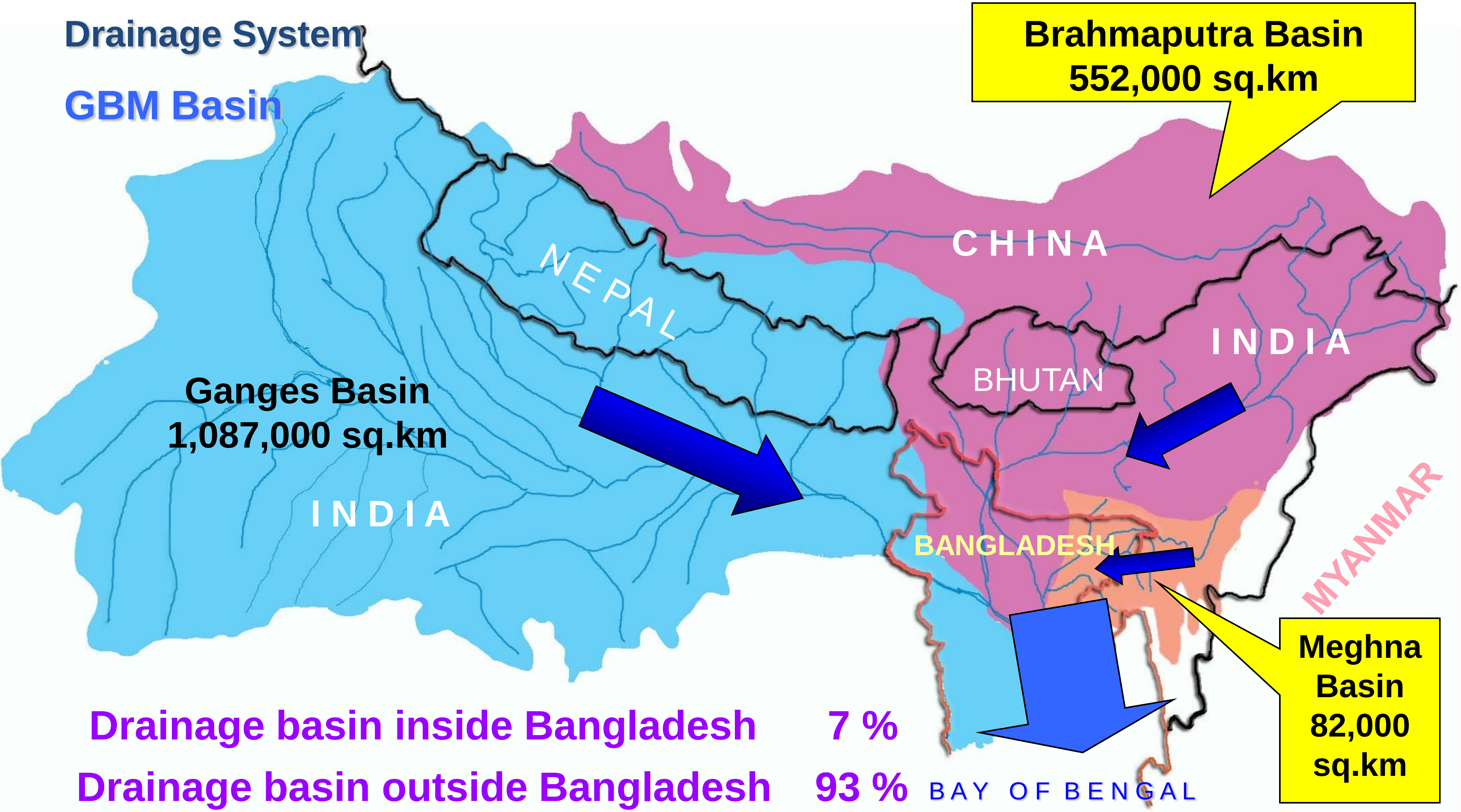
Surface water sources in Bangladesh

- ❑795,000 Million cubic meter surface water through the Ganges-Brahmaputra system (~5.52 m deep water over a land area of 144,000 cubic km)
- ❑Average annual rainfall 2.30 m replenishes surface water sources.
- ❑1,288,222 Ponds with an average area of 0.114 ha per pond (BBS, 1997) in the dry season.
- ❑Before the installation of tubewells, rural water supply was largely based on protected ponds.

Transboundary Rivers

Drainage System

GBM Basin



Drainage basin inside Bangladesh 7 %

Drainage basin outside Bangladesh 93 %

Topics to be covered in this class

- ❑ Tubewell Technology (shallow tubewell, deep set and intermediate, deep tubewells)
- ❑ Alternate water supply for problem areas
- ❑ Surface water collection and transportation
- ❑ Pumps and pumping machineries
- ❑ Water distribution systems
- ❑ Analysis and design of distribution network
- ❑ Fire hydrant
- ❑ Water meters
- ❑ Leak detection and unaccounted for water
- ❑ Water safety plan

Reference for this lecture

Chapter 16: Water Supply & Sanitation (Ahmed & Rahman)

Week-(02)

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Tubewell Technology in Bangladesh

Three broad categories

Shallow tubewells

- No.6 handpump tubewell
- Rower pump tubewell
- Disco pump tubewell

Draws water from a shallow depth (practically upto 7.5 m) and operated under suction

Deep-set intermediate technology

- Tara handpump tubewell
- Moon handpump tubewell
- Bangla handpump tubewell
- Mark-II handpump tubewell
- Other locally produced, improvised deep-set pumps

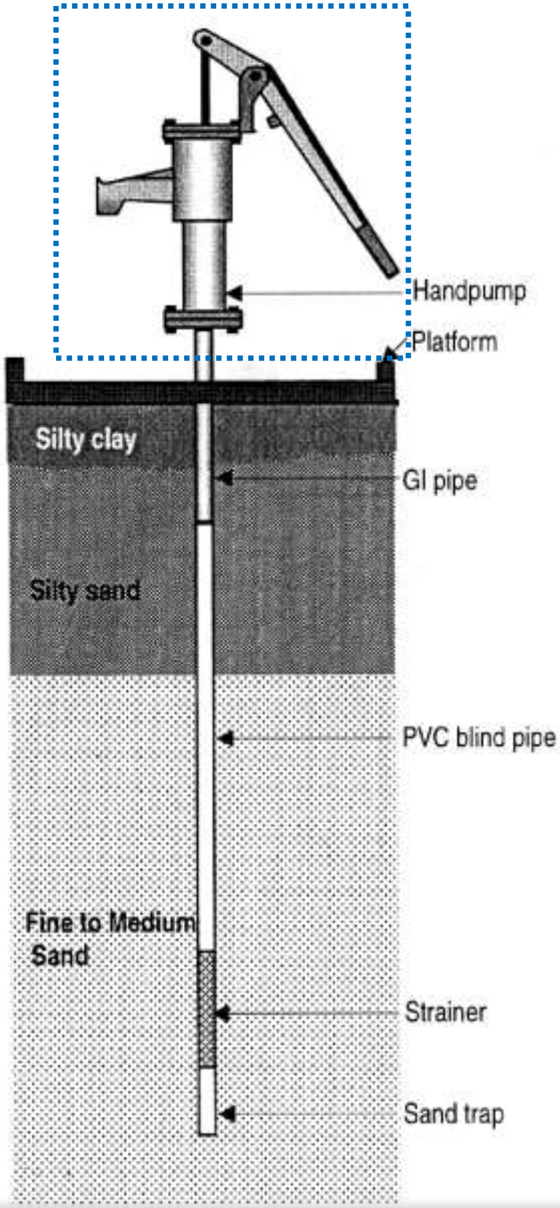
Water can be extracted from a depth beyond the suction limit (often as high as 30 m from static water level)

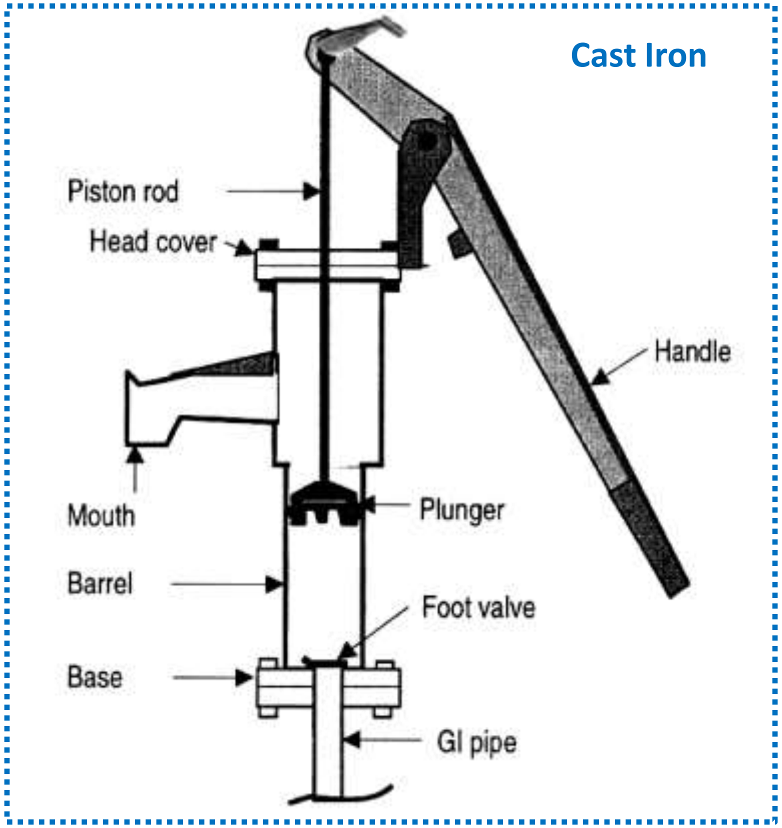
Deep tubewells

By definition a tubewell deeper than 75 m.

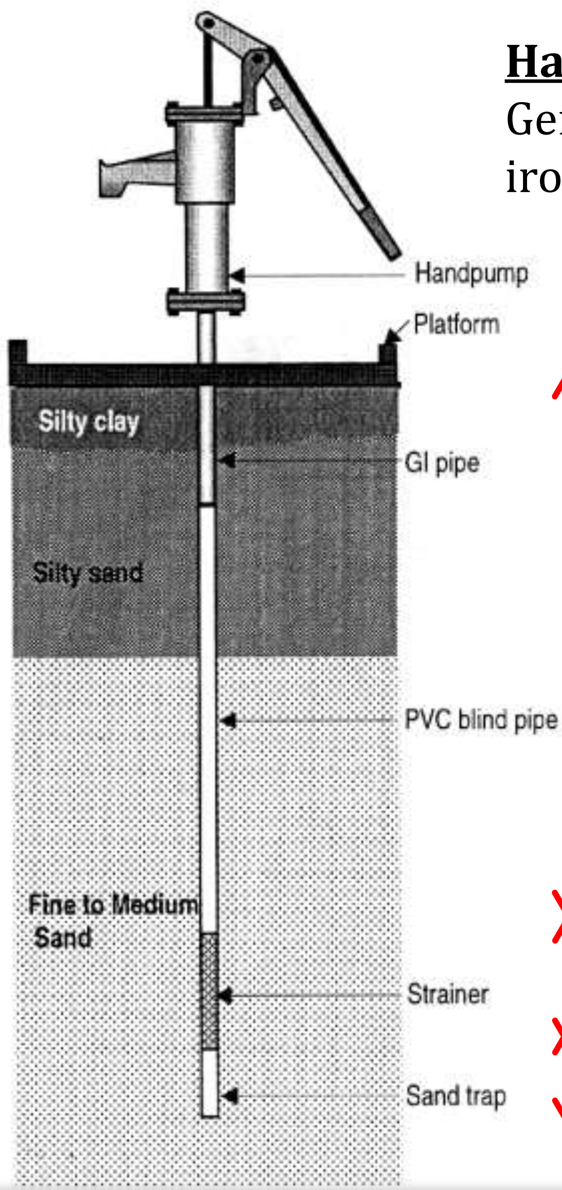
No. 6 Handpump Tubewell

❑Name based on its barrel diameter in inches.
❑Most common and popular technology in Bangladesh (~ 8 million in use)
❑Practical lifting capacity 22-25 ft, average discharge 30-40 L/min, usable for 15-20 years.





No. 6 Handpump Tubewell



Handpump:
Generally made of cast iron

Parts:
(1) handpump
(2) blind pipe
(3) strainer
(4) sand pipe

Blind pipe (~38 mm dia):
GI or PVC. GI more expensive. PVC pipes are corrosion resistant, easy to handle, inexpensive

Strainer ~(38 mm dia):
GI, MS, PVC or Stainless steel. Openings are 0.008" (slot no. 8), 0.010" (slot no. 10), 0.012" (slot no. 12)

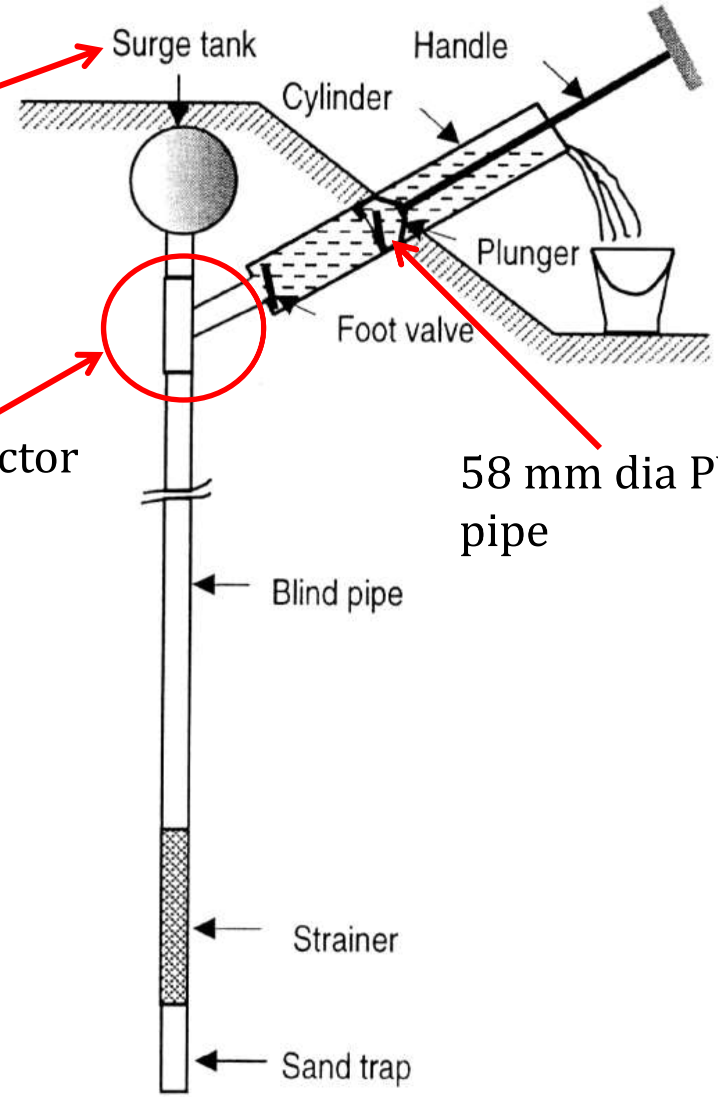
Sand trap (GI or PVC):
To accommodate incoming sand, prevents blockage of strainer

Rower Pump Tubewell

Partially eliminates the effect of inertia

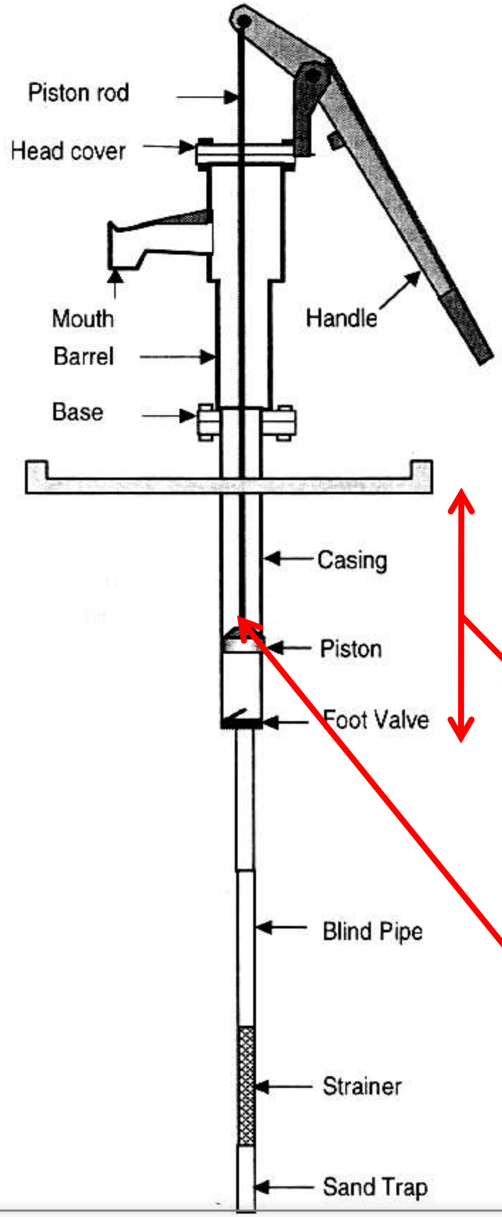
Y connector

58 mm dia PVC pipe



- ❑Name based on its operation mode which is like rowing a boat
- ❑Mostly used for irrigation purposes and occasionally for domestic purposes
- ❑Ergonomically comfortable
- ❑Practical lifting capacity 8.5 m, average discharge 0.8 L/s, usable for 15-20 years.

Disco Handpump Tubewell

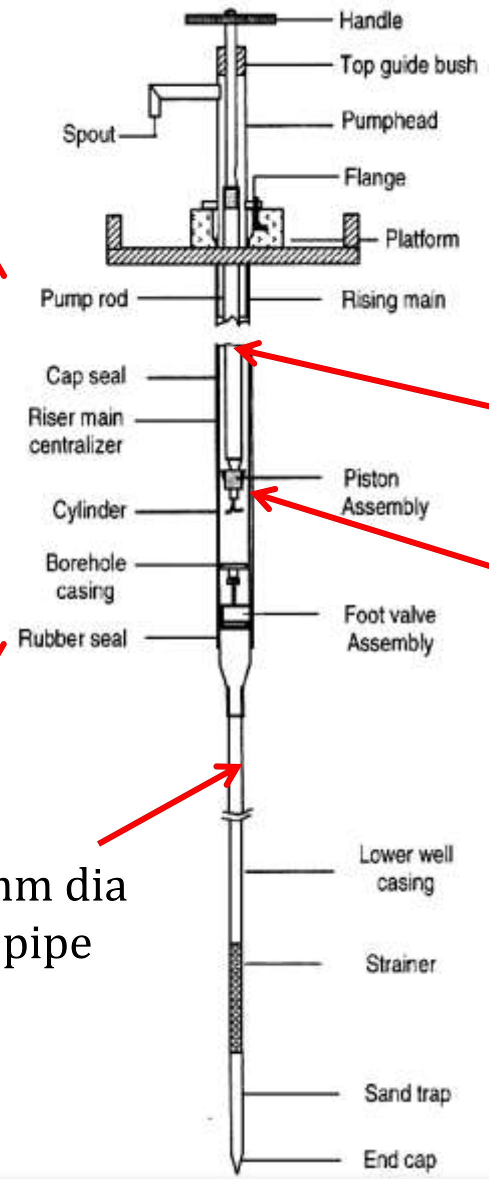


- Also known as half-cylinder pump (in Gazipur)
- Same operational principle as No.6 pump except with an extended casing and comparatively more force to lift water
- Can only be used where water table remains 10 m within the ground surface.
- This tubewell will become expensive if the lift head becomes higher.

GI pipe (75 mm dia):
Exteded upto 3 m below ground surface

Extended piston

Tara Handpump Tubewell



75 mm dia casing extended to 18 m below GL

38 mm dia PVC pipe

- Developed by UNDP-World Bank and UNICEF
- Lifting capacity limited to 15 m, average discharge 25 L/min

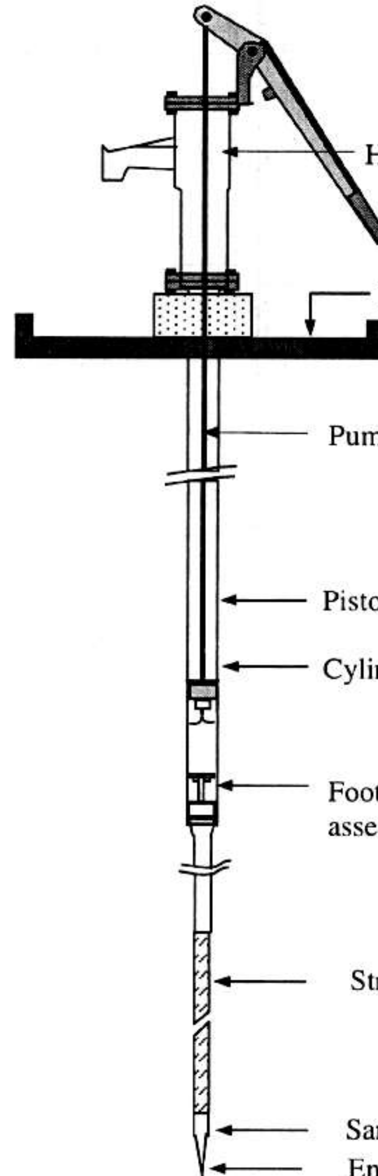
32mm dia hollow PVC pumprod reduces the manual force required to operate the pump

Piston of the pump operates below groundwater level

Tara-II handpump tubewell
Same as Tara tubewell except with a lower pumping mechanism (piston assembly set at 30 m) and with a No.6 pump head with lever action handle

Moon Handpump Tubewell

- ❑Same as Tara tubewell except with a No. 6 head assembly and the PVC pumprod is replaced by a steel rod
- ❑Maximum discharge 36 L/min and suitable for lifting water upto 25 m.



<u>Other variations of the moon and tara handpump tubewells</u>

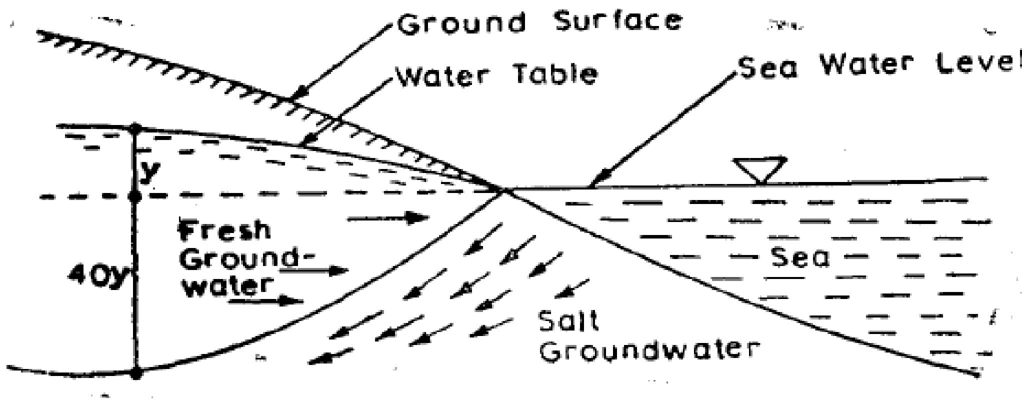
Bangla handpump tubewell (smaller upper wall casing)

Mark II handpump tubewell (used a connecting rod, increased length of handle to enhance lever action)

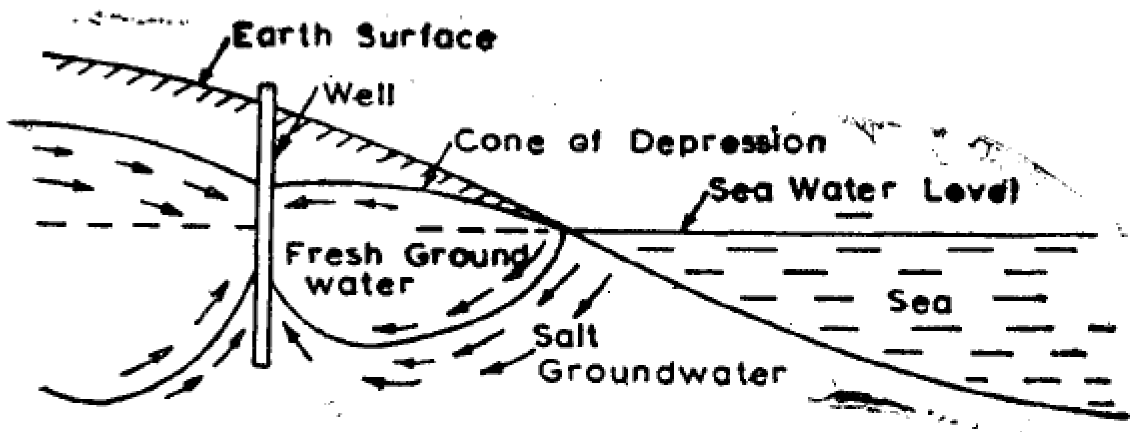
Alternative Water Supply Technologies

- Shallow Shrouded Tubewell (SST)
- Very Shallow Shrouded Tubewell (VSST)
- Pond Sand Filter (PSF)
- Household filters
- Infiltration Gallery
- Solar Desalination
- Rainwater Harvesting

Saltwater Intrusion in Coastal Areas



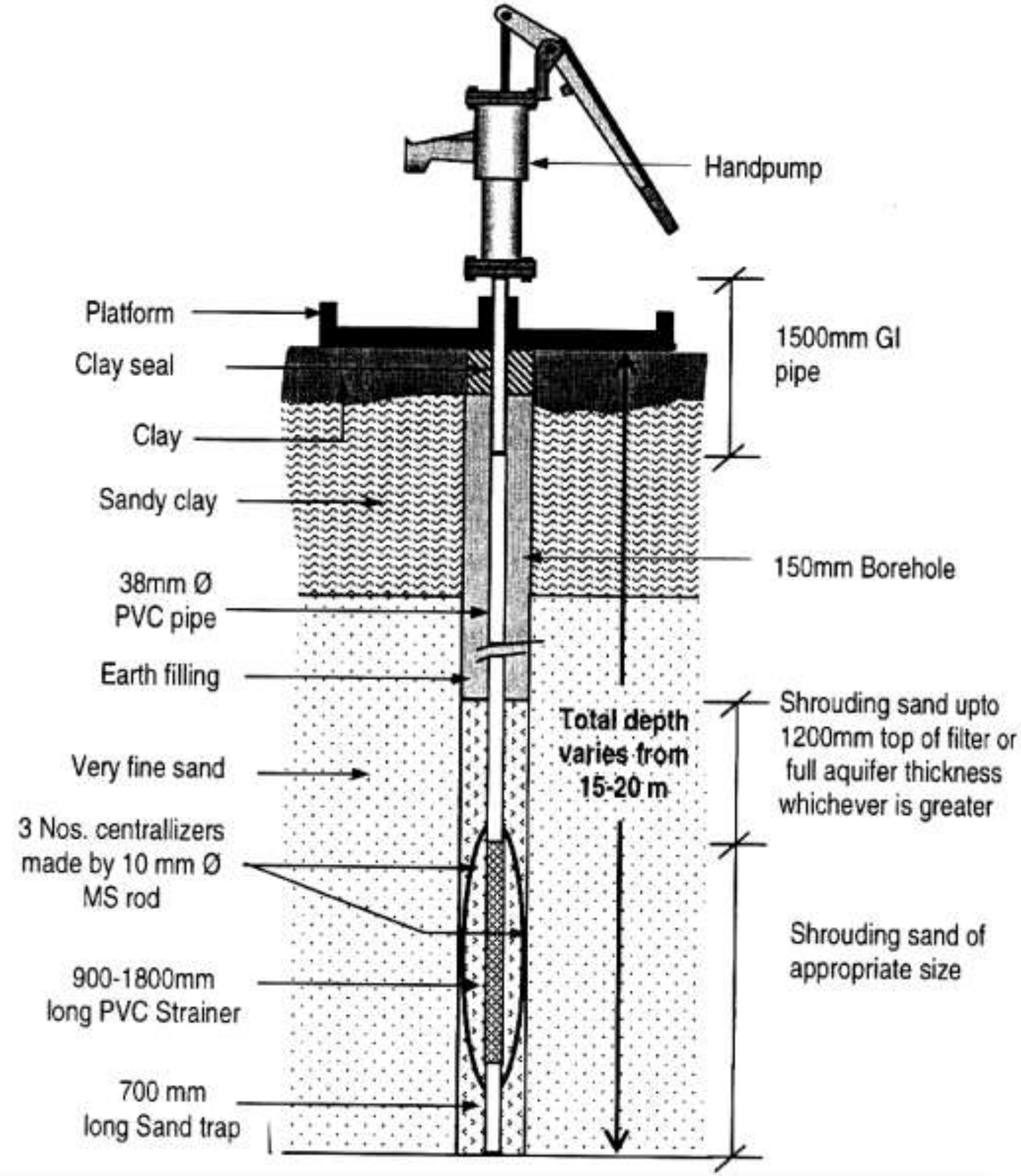
Hydrostatic equilibrium requires a freshwater column ~1.025 high as a saltwater column



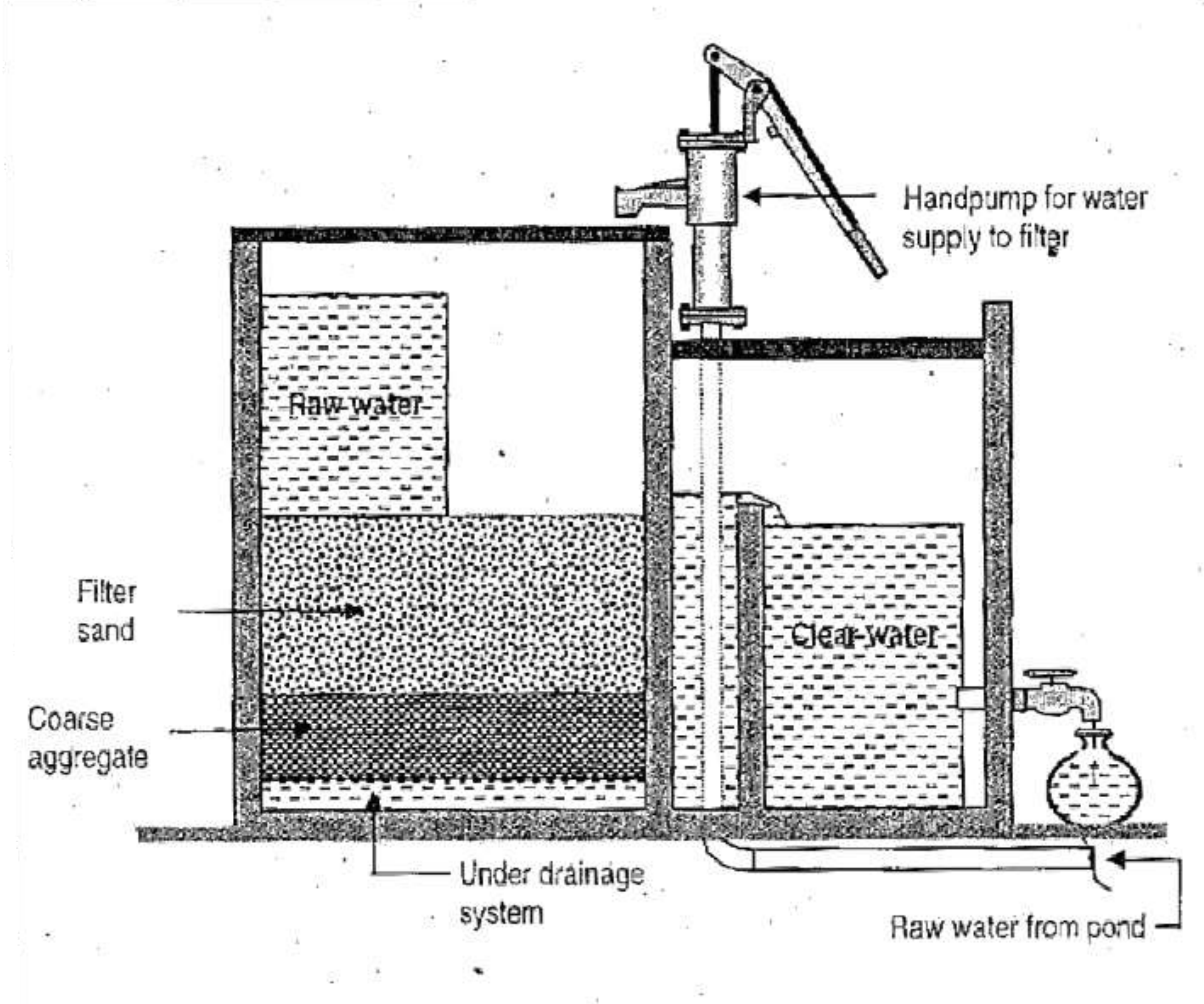
Pumping by wells disturbs this equilibrium, an inverted cone of saltwater rises under the well. (approx. 40 ft rise of saltwater for 1 ft drawdown of freshwater)
<u>Solution</u>: radial wells, recharge wells

Shallow Shrouded Tubewell (SST)

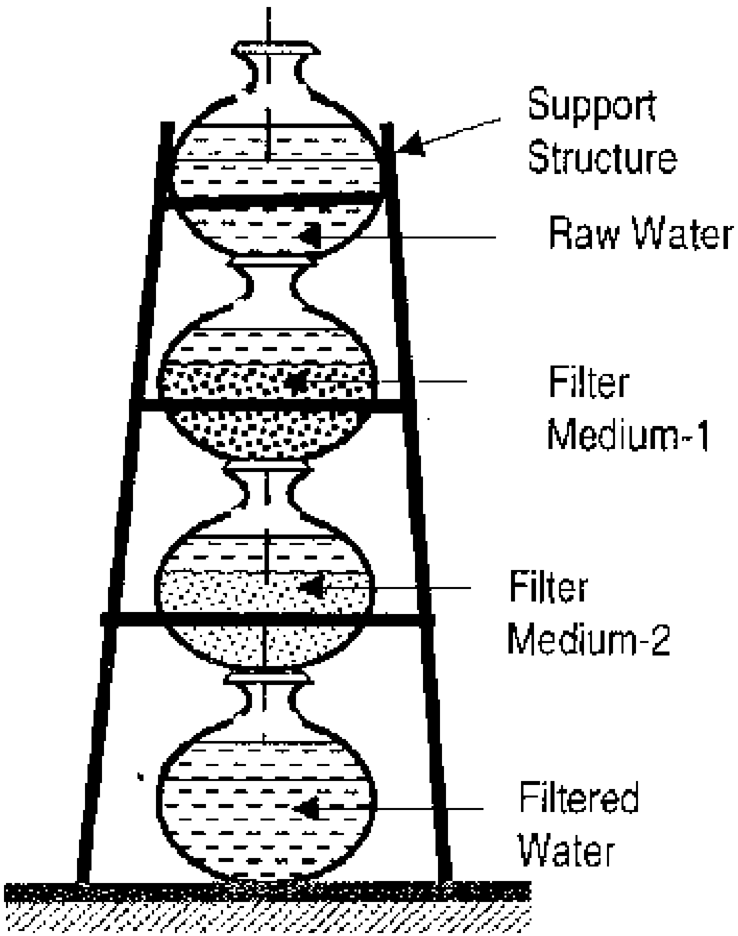
- In coastal areas, freshwater is available in shallow aquifers at 15-20 m depth but installing regular tubewells are not feasible because of the particle size (very fine sand)
- Artificial sand packing (shrouding) is used around the screen and prevents entry of fine sand into the screen.
- Another configuration of this tubewell which draws water from a shallower depth (8 m) is called a Very Shallow Shrouded Tubewell (VSST)

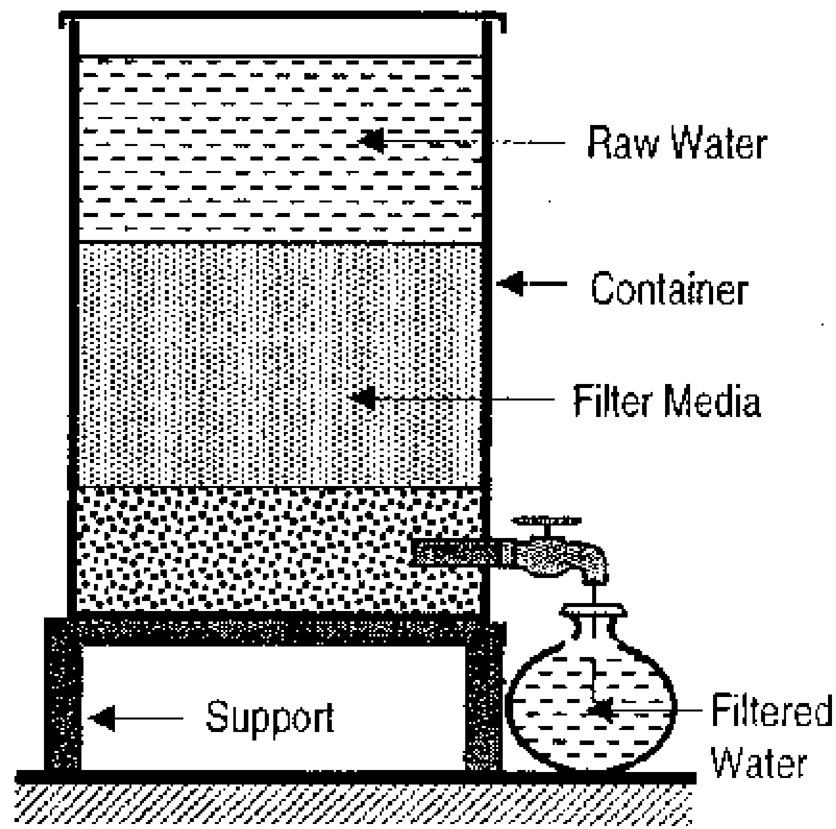


Pond Sand Filter (PSF)

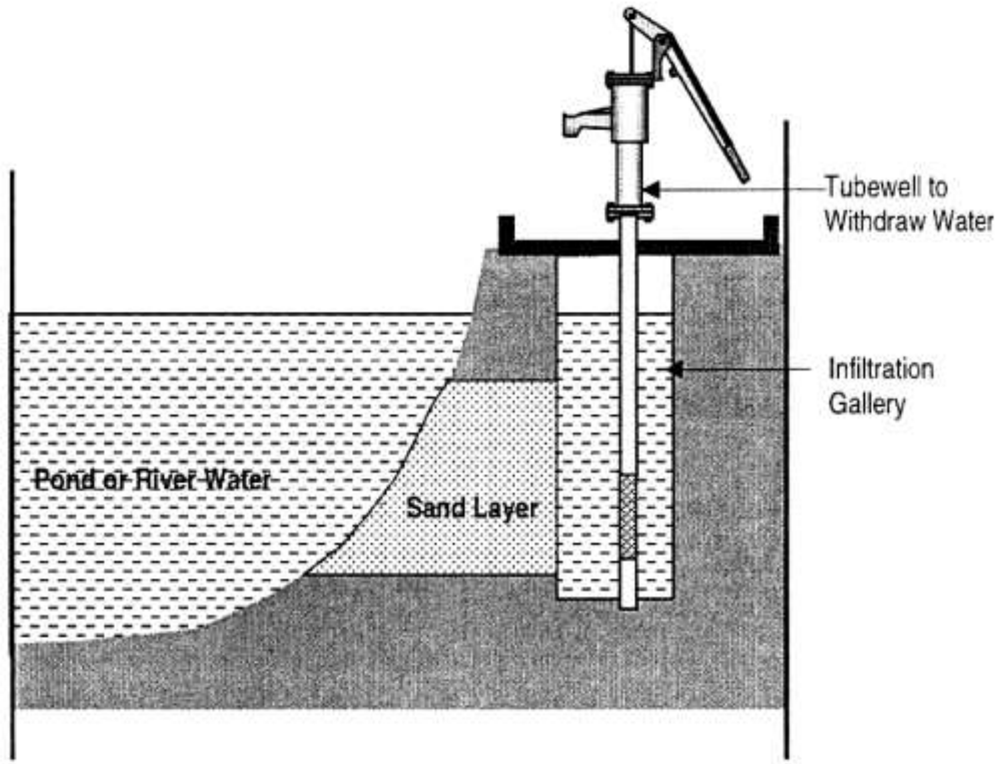


Household Filters





Infiltration Gallery

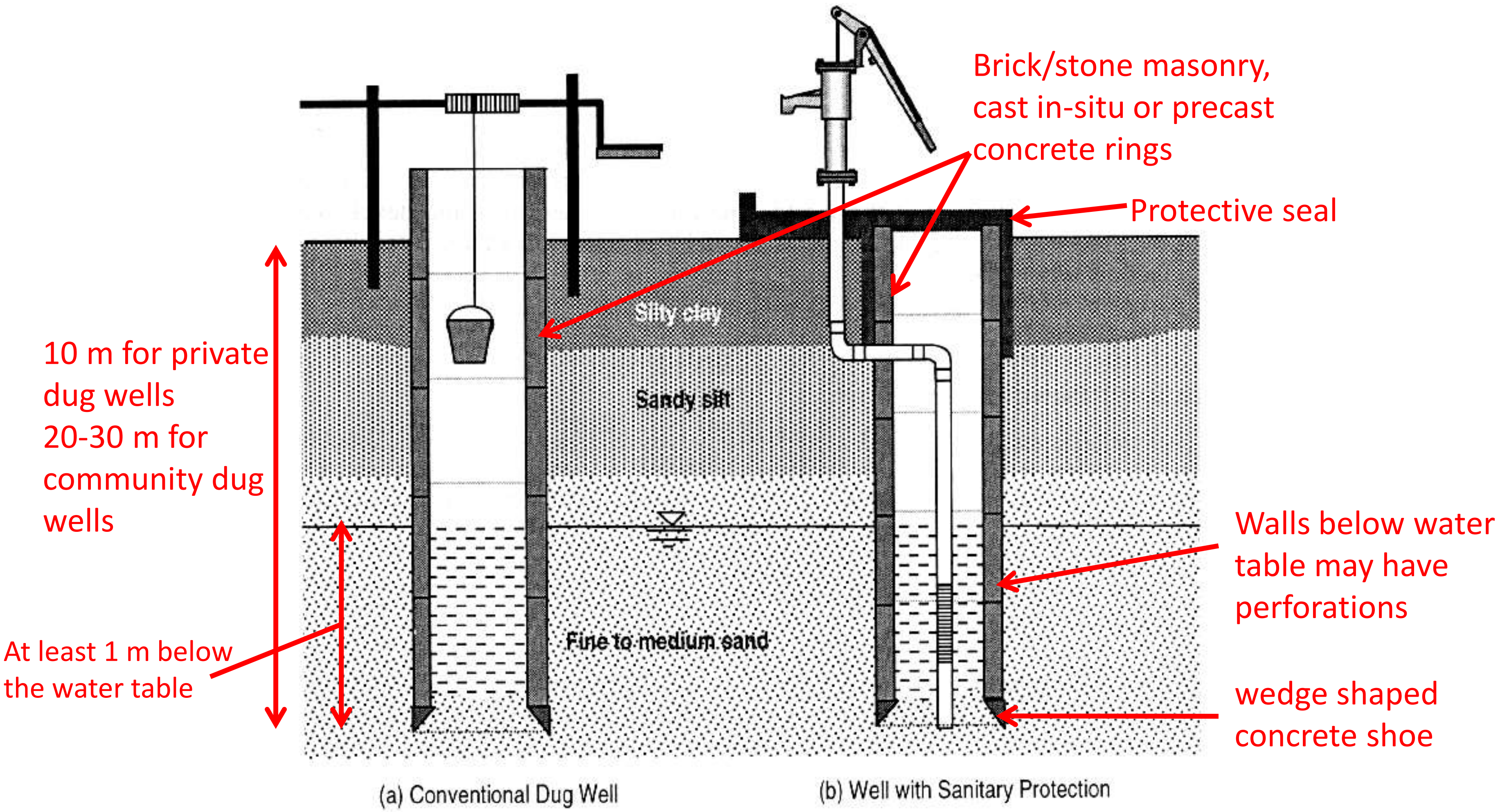


❑A buried trench placed in the direction perpendicular to the groundwater flow.

❑A river or pond with sandy soils are most suitable locations. Sometimes sand beds are placed for filtration of water.

❑Installation of handpump tubewells to collect water from sealed infiltration well can provide good sanitary protection.

Dug Wells



- ❑Chlorination for disinfection may be continued during operation.
- ❑Dug well water is generally free from Iron and Arsenic.

Alternate Water Source: Rainwater

Possibilities

- ❑Average annual rainfall in Bangladesh is 2400 mm (more than 3000 mm in coastal and hilly areas)
- ❑Water quality is comparatively good.
- ❑Installation easy, no energy cost, easy to maintain and operate.

Problems

- ❑Devoid of essential minerals (e.g. Calcium and Fluorides), has a flat taste and may cause nutrition deficiencies
- ❑Uneven spatial distribution of rainfall intensity.
- ❑Some treatment will be necessary (pollution due to debris, wind-blown dirt, bird droppings)
- ❑High initial cost (may not be affordable for the poorer segment of the population)

Reference for this lecture

Chapter 21: Water Supply & Sanitation (Ahmed and Rahman)

Saltwater intrusion: Water Supply Engineering (M.A. Aziz)

Week-(03)

MD Ehasan Kabir

Intake Structure

- **Objective:**

Selectively withdraw the best quality water while excluding fish, floating debris, coarse sediment and other objectionable suspended matter

- **Types:**

  Floating intakes

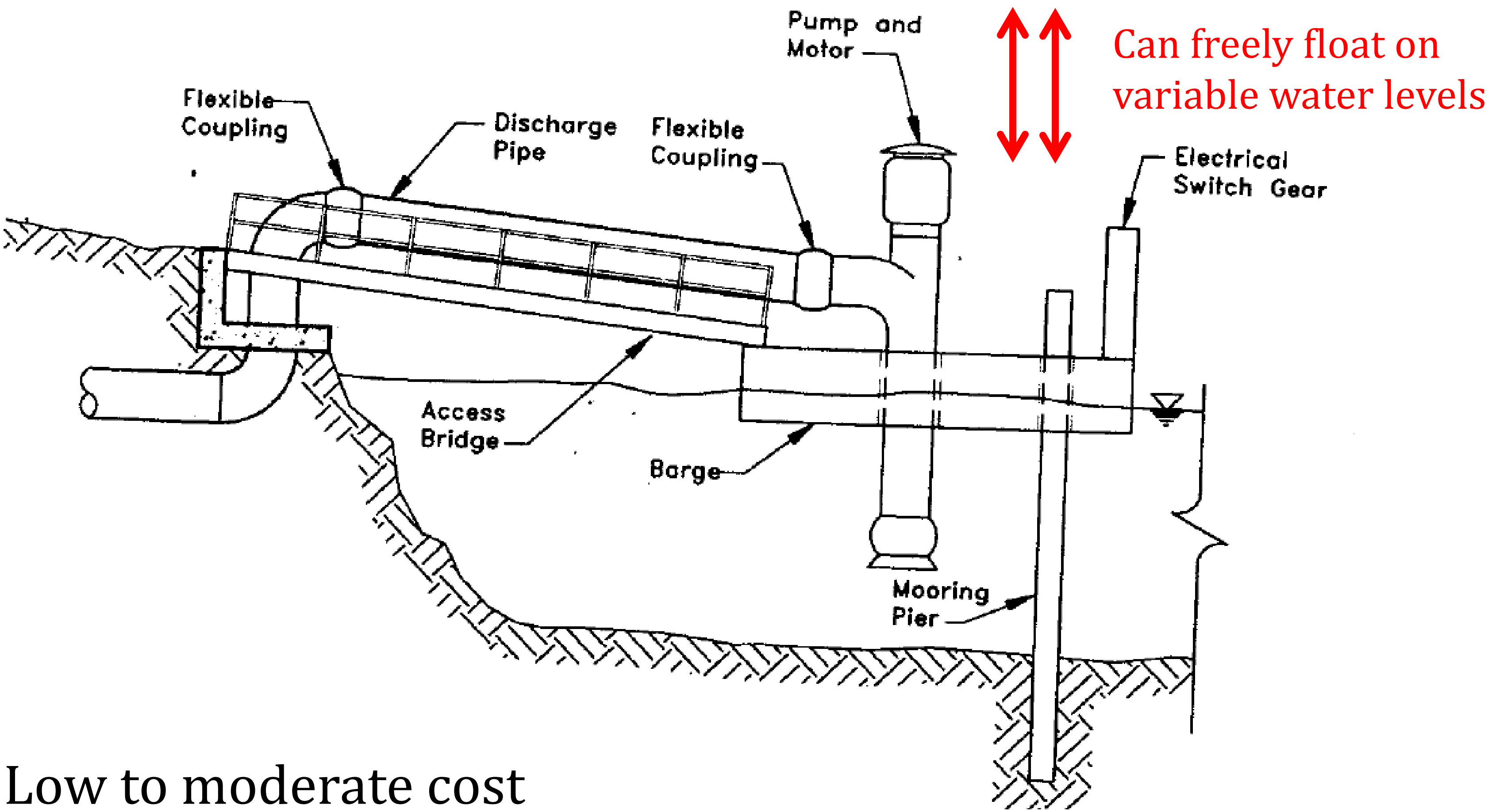
  Exposed or tower intakes

  Submerged intakes

  Shore and pier intakes

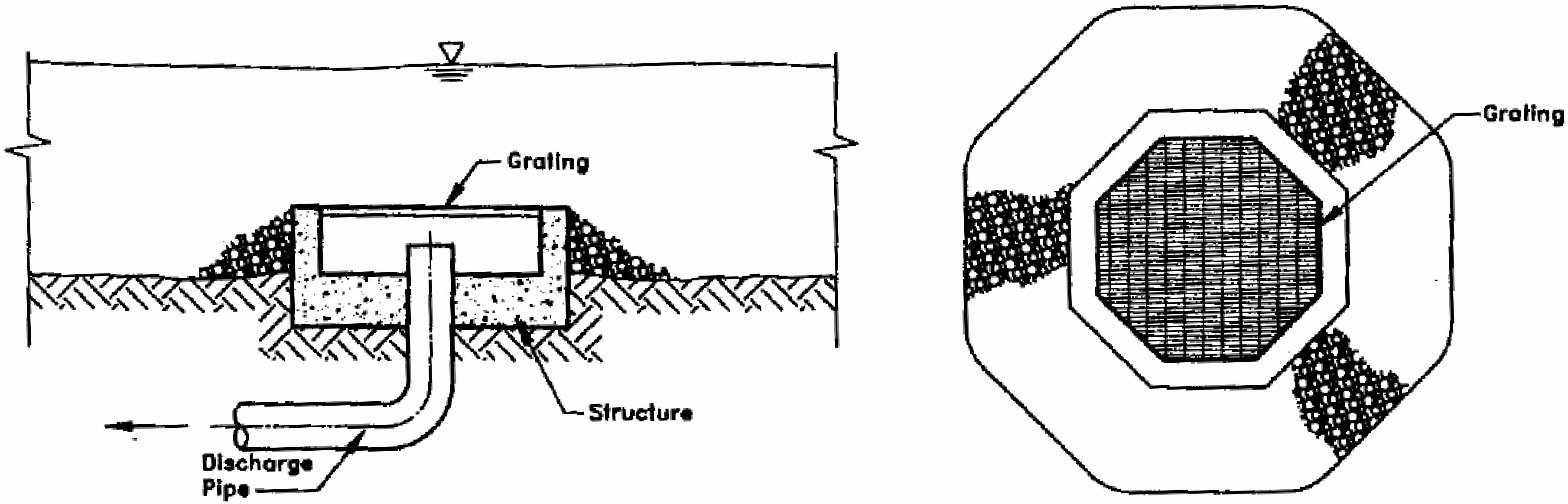
Components: Intake gates, valves, pumps, chemical feeders, flow meters, offices, machine shops etc.

Floating Intake



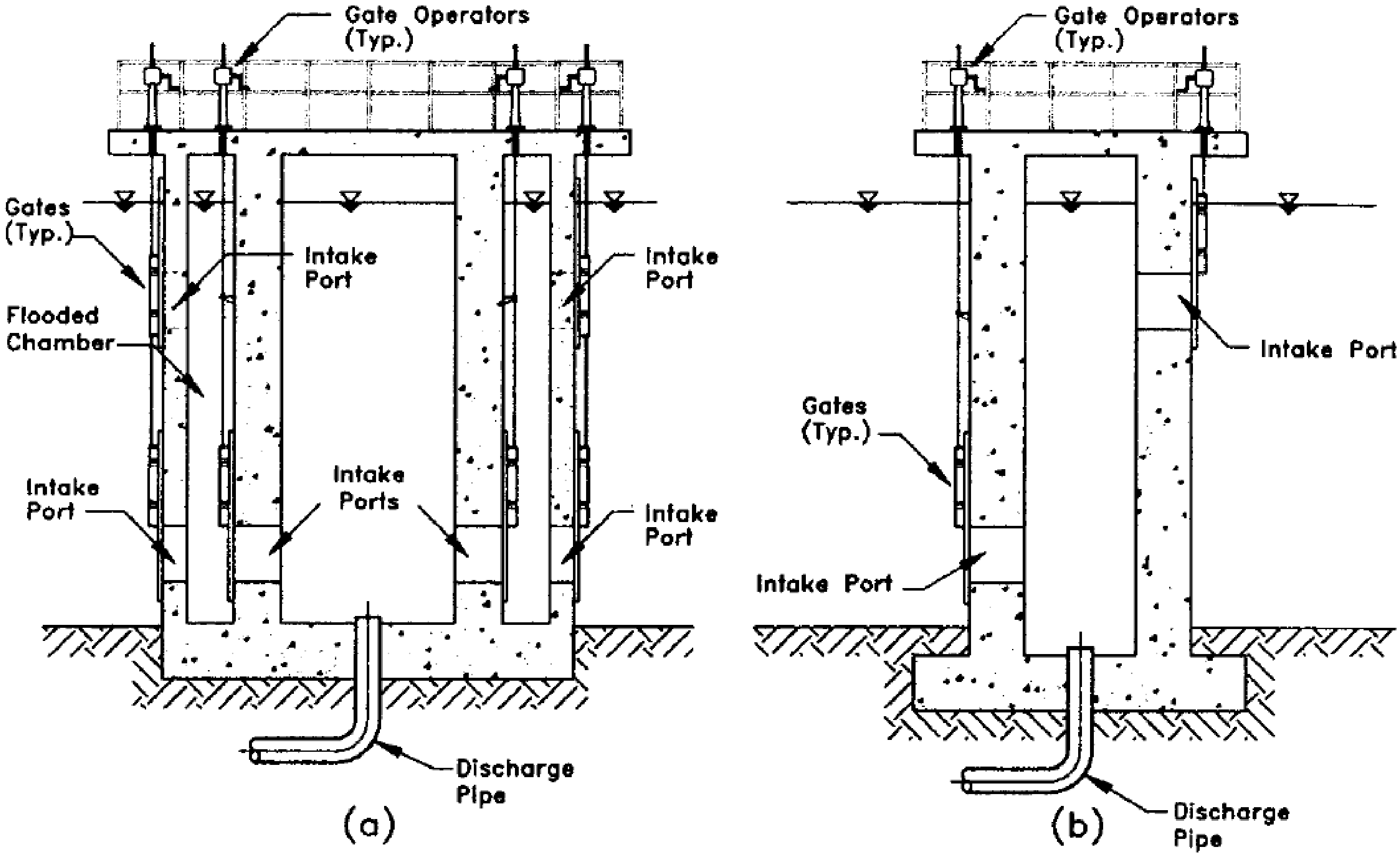
- ❑ Low to moderate cost
- ❑ Can be fabricated off-site and assembled onsite
- ❑ Damages due to wind and wave action if not properly anchored

Submerged Intake



- Simple, easy and relatively inexpensive
- Intake opening may be raised 1-2 m in lakes with heavy siltation
- Maintenance difficult, can only draw water from a fixed elevation near bottom where water quality is usually poor

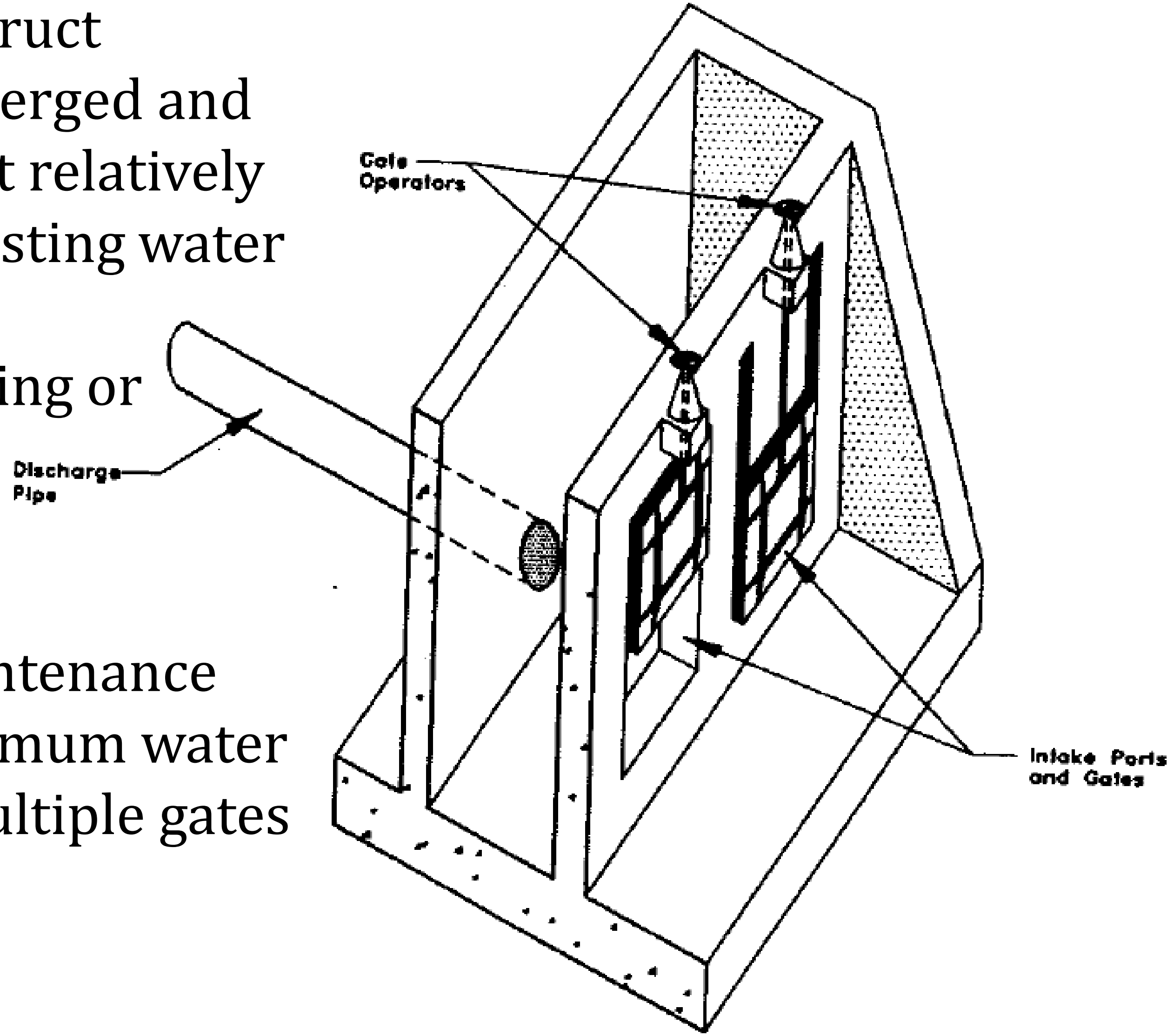
Intake Towers



- ❑ Expensive to construct, may be less accessible
- ❑ Can withdraw optimum water quality through multiple gates

Shore Intakes

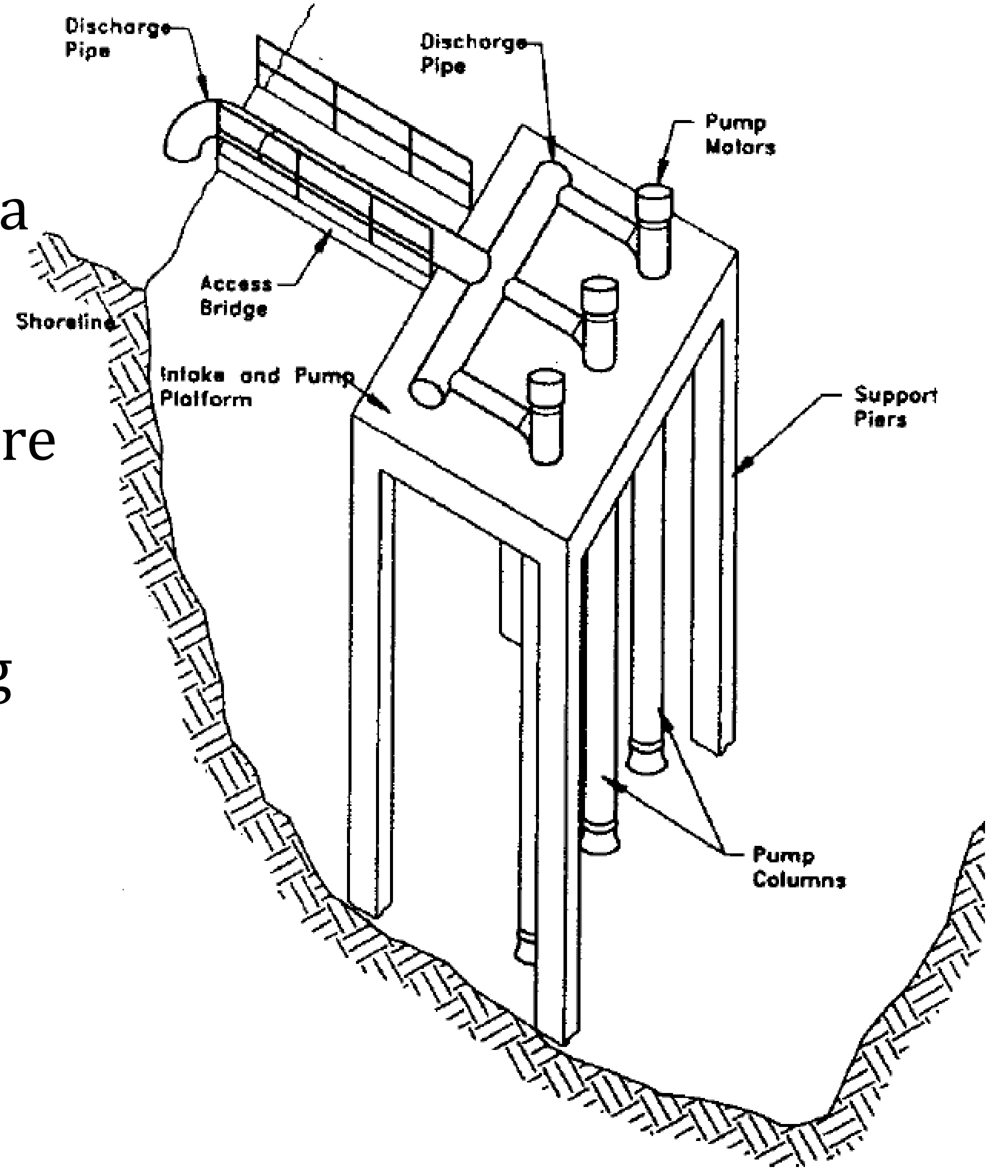
- Expensive to construct compared to submerged and floating intakes but relatively inexpensive for existing water bodies
- May require dredging or excavation



- Accessible for maintenance
- Can withdraw optimum water quality through multiple gates

Pier Intakes

- ❑ Used on lakes and rivers where water depth at shoreline is too shallow for a shore intake
- ❑ Can withdraw water with optimum quality if pumps are installed at different elevations
- ❑ Easy to construct in existing water bodies, accessible for maintenance



Considerations for Intake Site Selection

- ❑ Water Quality
- ❑ Water Depth
- ❑ Stream or current velocities
- ❑ Foundation Stability
- ❑ Access to site
- ❑ Power Availability
- ❑ Proximity to Water Treatment Plant
- ❑ Environmental Impact

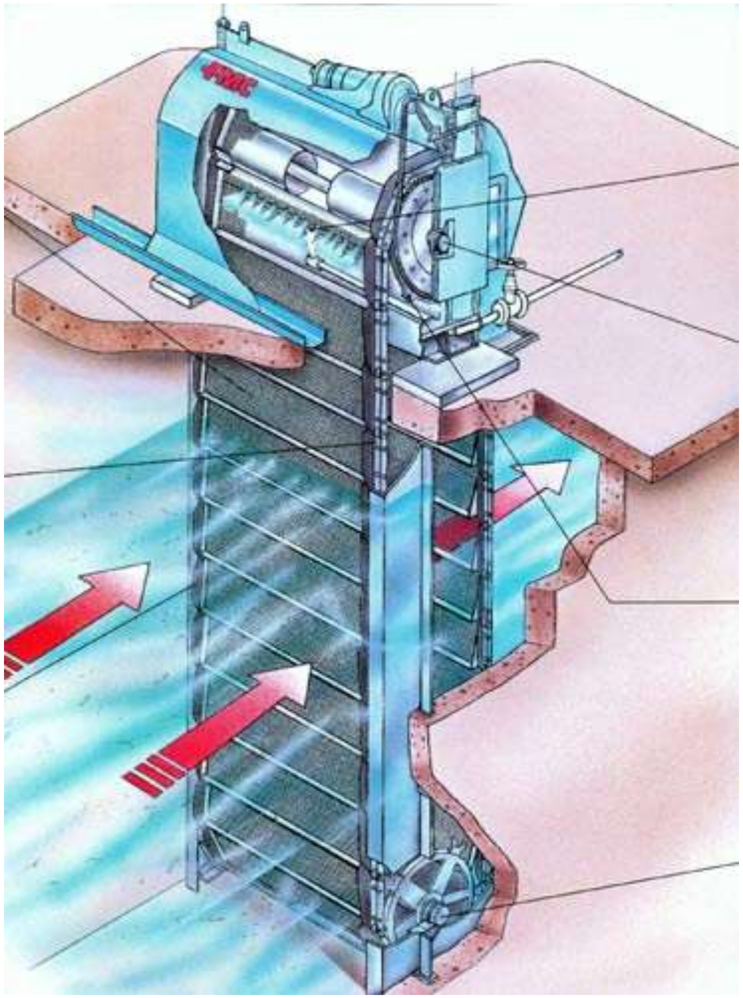
Intake Design Considerations

- **Intake Velocity**: velocity below 0.3 fps allows fish to escape, reduces ice problems and reduce entrainment of suspended matter
- **Intake Port Location**:
  - multiple intake ports at several elevations are preferable
  - location of ports determined by testing water quality
  - topmost port not less than 2m below water surface
  - bottom port at least 1 m above bottom
- **Gates**: Sluice gates typically used to control flow of water from source to the water conveyance system
- **Control of Ice**: (for colder regions)
  - keep intake ports sufficiently below water level
  - steam piping, compressed air, space heaters

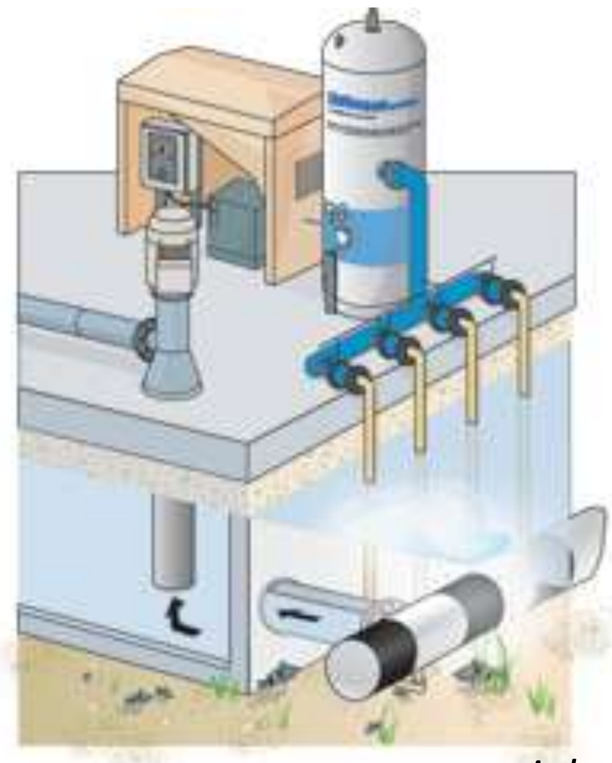
Screening

- ❑ **Coarse Screen**:
  - bar racks with 2-3” clear spacing
  - should be installed in the outside
  - provision for cleaning
- ❑ **Fine Screen**:
  - to remove smaller objects that might damage pumps
  - heavy wire mesh having 0.25” square openings
  - design velocity 0.4 – 0.8 m/s
  - requires frequent cleaning (travelling screens used often)
- ❑ **Microstrainer**:
  - to remove plankton and algae (to improve sedimentation and chlorination performance)
  - fine wire mesh
  - slime build up
  - will not handle sand, silt and abrasive material

Traveling and Passive Fine Screens

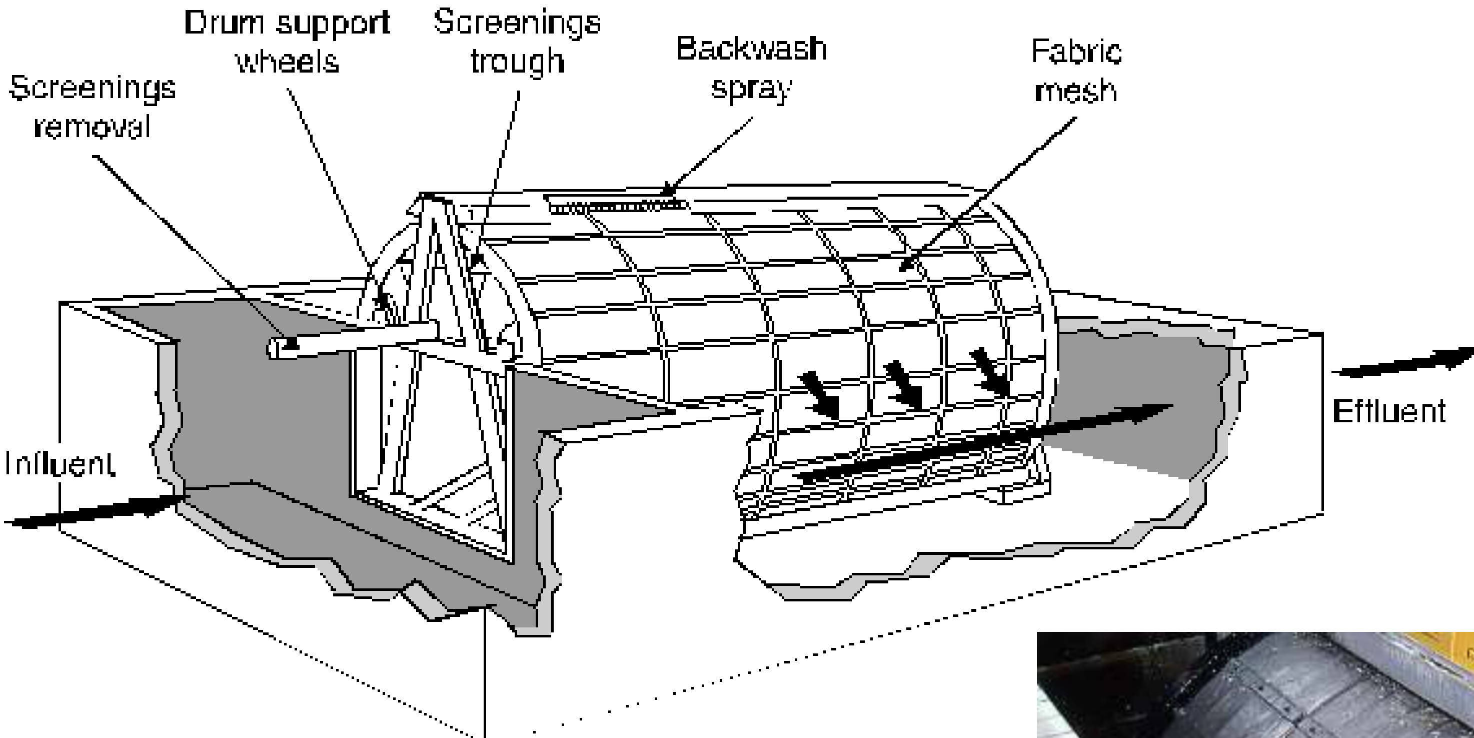


www.power-technology.com



www.johnsonscreens.com

Microstrainer



www.staffs.ac.uk

Sharulia Intake Station, SWTP, Dhaka WASA

Bar screens on the outside

Sharulia Intake Station, SWTP, Dhaka WASA

River Training Works to protect the banks beside the intake

Additional screens before pumping

Sharulia Intake Station, SWTP, Dhaka WASA

Sluice Gates to Control the flow

Inside the pump house

Sharulia Intake Station, SWTP, Dhaka WASA

Water is pumped and discharged to WASA Conveyance Canal

WASA Conveyance Canal

Design of Intake and Screens

- **Head Loss (m) through intake port (orifice equation)**:

$$H_L = \frac{1}{2g}\left(\frac{v}{C_d}\right)^2$$

v = velocity, m/s
C_d= coefficient of discharge for orifice, 0.6 – 0.9

- **Head Loss (m) through screens**:

$$H_L = \frac{v^2 - {v_v}^2}{2g} \times \frac{1}{0.7}$$

v = velocity through the screen opening, m/s
v_v= velocity upstream of the screen (0 in most cases), m/s

Design Example

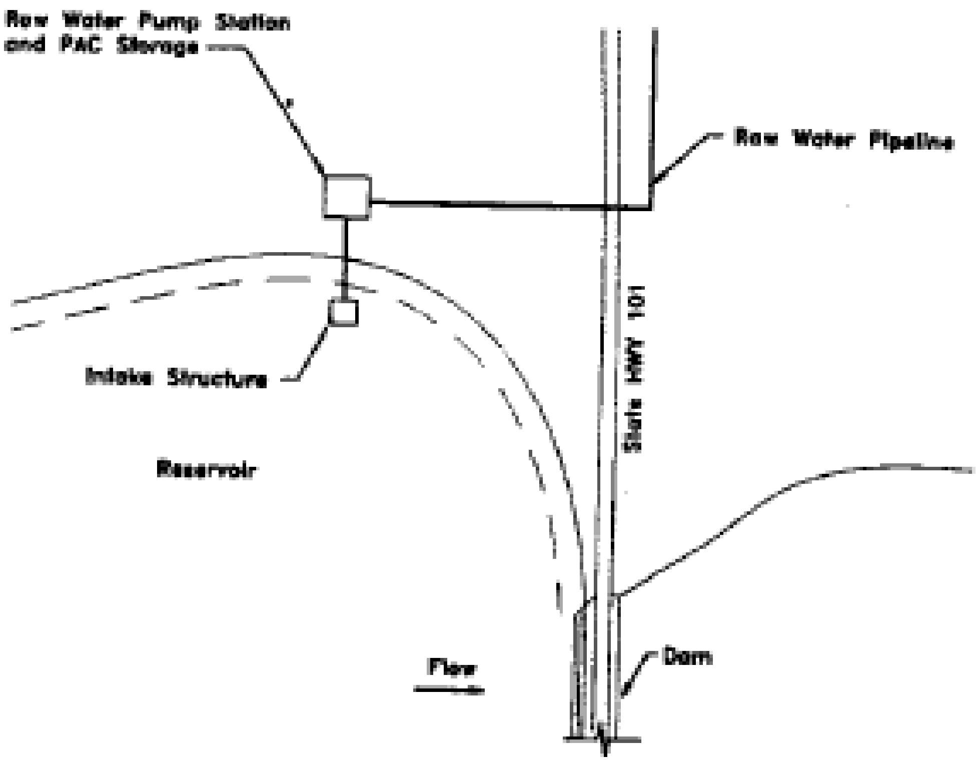
- **Hydraulic data**
  a. Design flow = 113500 m^3/day
  b. Minimum reservoir elevation = 70 m (MSL)
  c. Maximum reservoir elevation = 90 m (MSL)
  d. Normal water surface elevation = 85 m (MSL)
  e. Bottom elevation = 60 m (MSL)

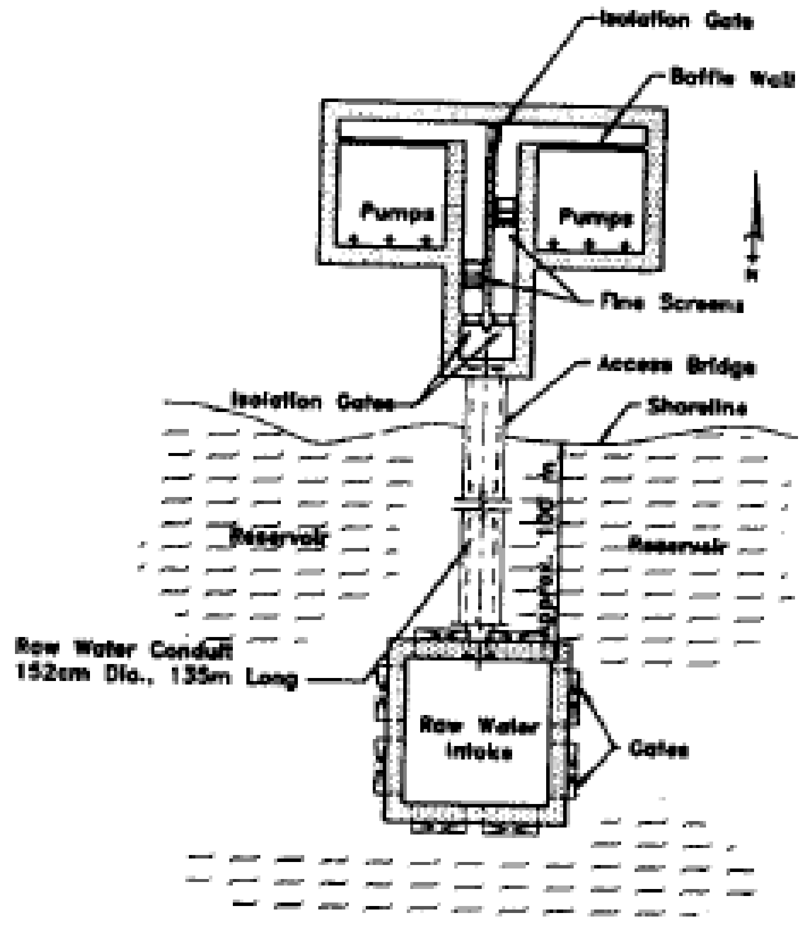
- **Design Guidelines**:
  a. Intake will withdraw water from max 90 m and min. 70 m
  b. Dry tower design with several gates at different elevations
  c. Coarse screen will be provided at each gate
  d. A mechanically cleaned fine screen shall be provided at the pump station
  e. velocity through the bar rack < 8 cm/s (0.3 fps) and the fine screen < 0.2 m/s (0.6 fps)

Design Example

- **Location and configuration of headworks**

  In a lake, connected by bridge to the onshore pump station





Reference for this Lecture

Chapter 6: Water Works Engineering (by Qasim and co-authors)
[photocopy of the chapter provided in class]

Week-(04)

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When pumps are required

- When the elevation of the source of water supply is such that the water will not flow into the mains by gravity
- When it is required to increase or boost up pressure in the mains
- When water has to be lifted from one level to another.

Pump Classification

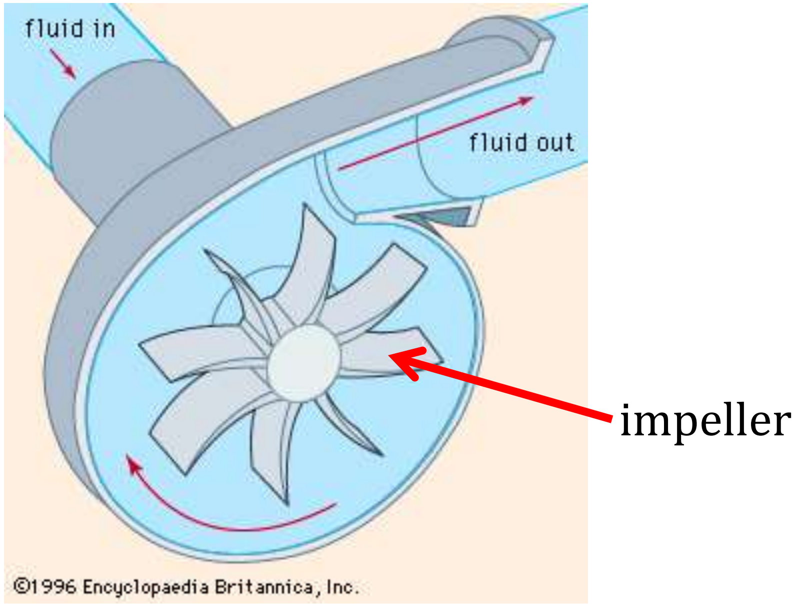
Based on type of service	Based on power used	Based on mechanical principles of operation
(1) Deep well pumps (2) Low lift pumps (3) High lift pumps (4) Booster pumps (5) Fire service pumps (6) Stand-by pumps	(1) Steam pumps (2) Gasoline pumps (3) Diesel pumps (4) Electric pumps	(1) Displacement pumps (2) Centrifugal pumps (3) Air lift pumps

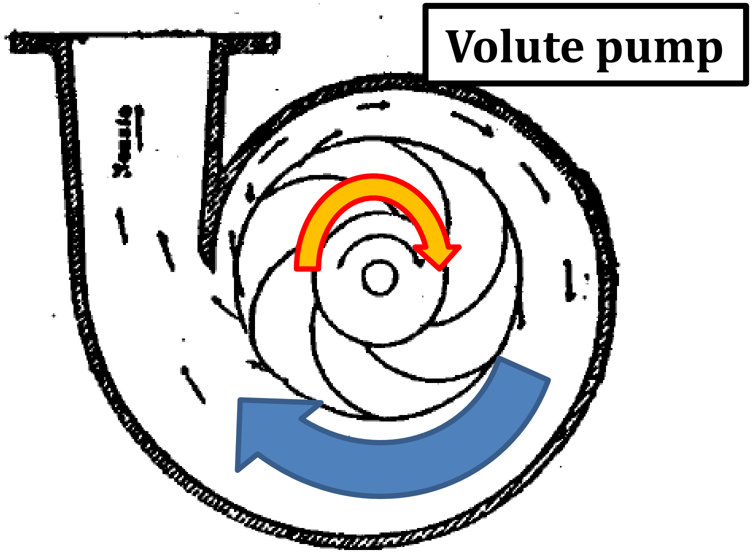
Most commonly used in water works (no smoke or dust, no noise, economical operation, economy in floor space)

Extensively used in modern water works (relatively cheap, compact and simple and adaptable to various kinds of power)

Centrifugal Pump

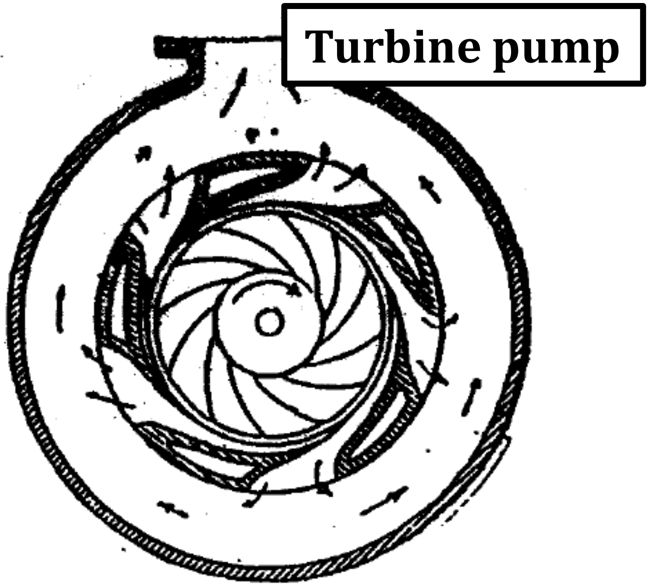
Uses centrifugal force to impart energy to water





Kinetic energy of water is converted to static head

Can be single-stage, two-stage or multiple stage pumps



Centrifugal Pump: Merits and Demerits

Merits:

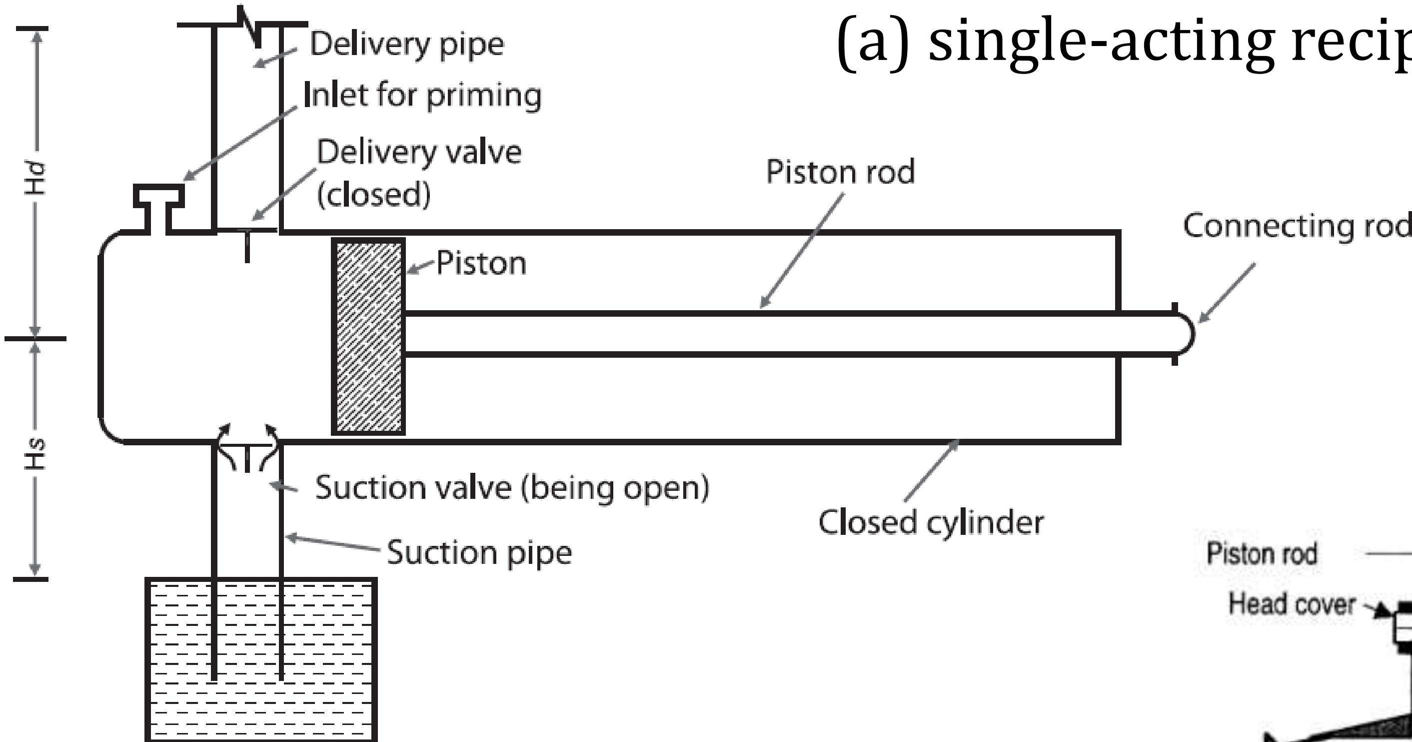
- Low initial costs
- Simple mechanism, simple operation and repair
- Stability of flow
- Safe against high pressures
- Adaptability to high heads
- Small space requirement
- Good durability

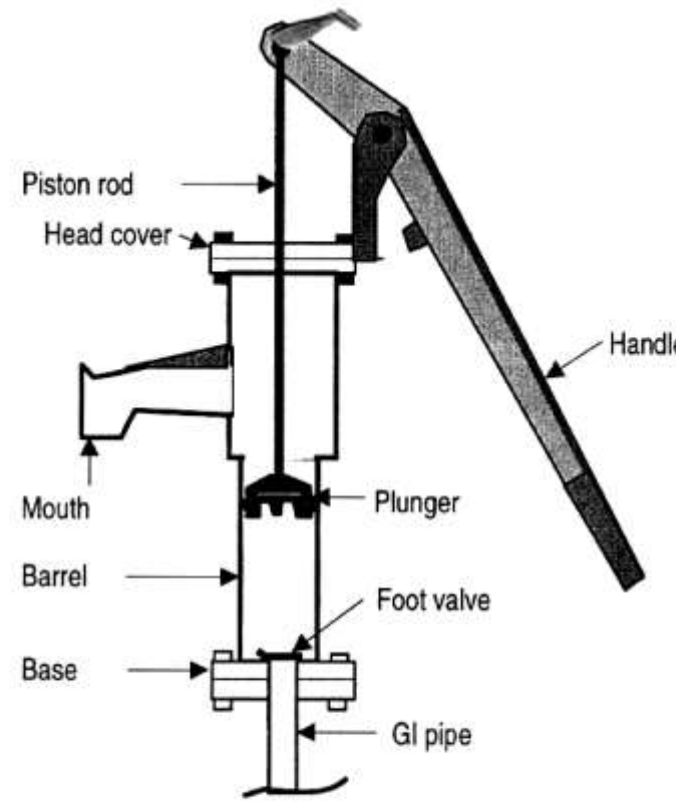
Demerits:

- Limited suction lift
- No self-priming arrangements
- Speed regulating gears required to adjust speed
- Low efficiency over a wide range of H and Q

Displacement Pumps

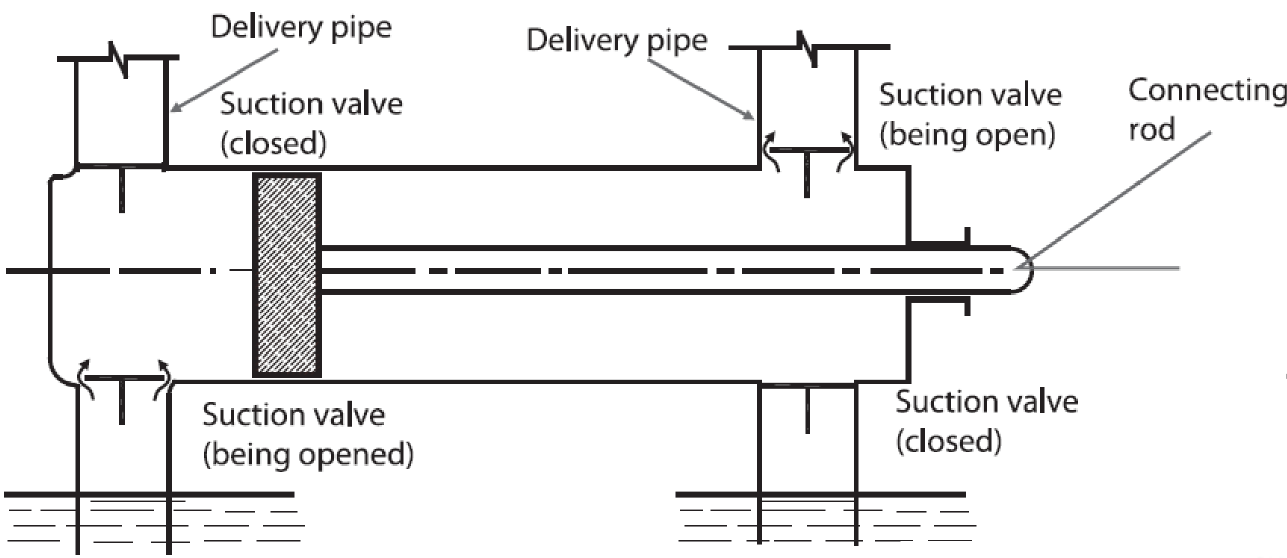
(a) single-acting reciprocating type





Mechanically induces vacuum in a chamber to draw water in and eventually forcing the water out of the chamber

Displacement Pumps

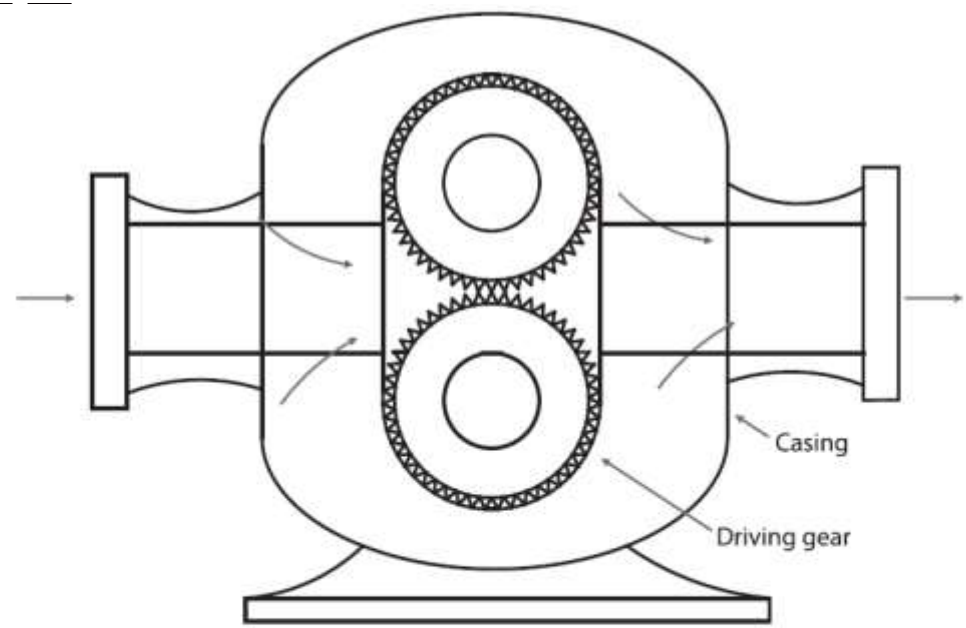


(b) double-acting reciprocating type

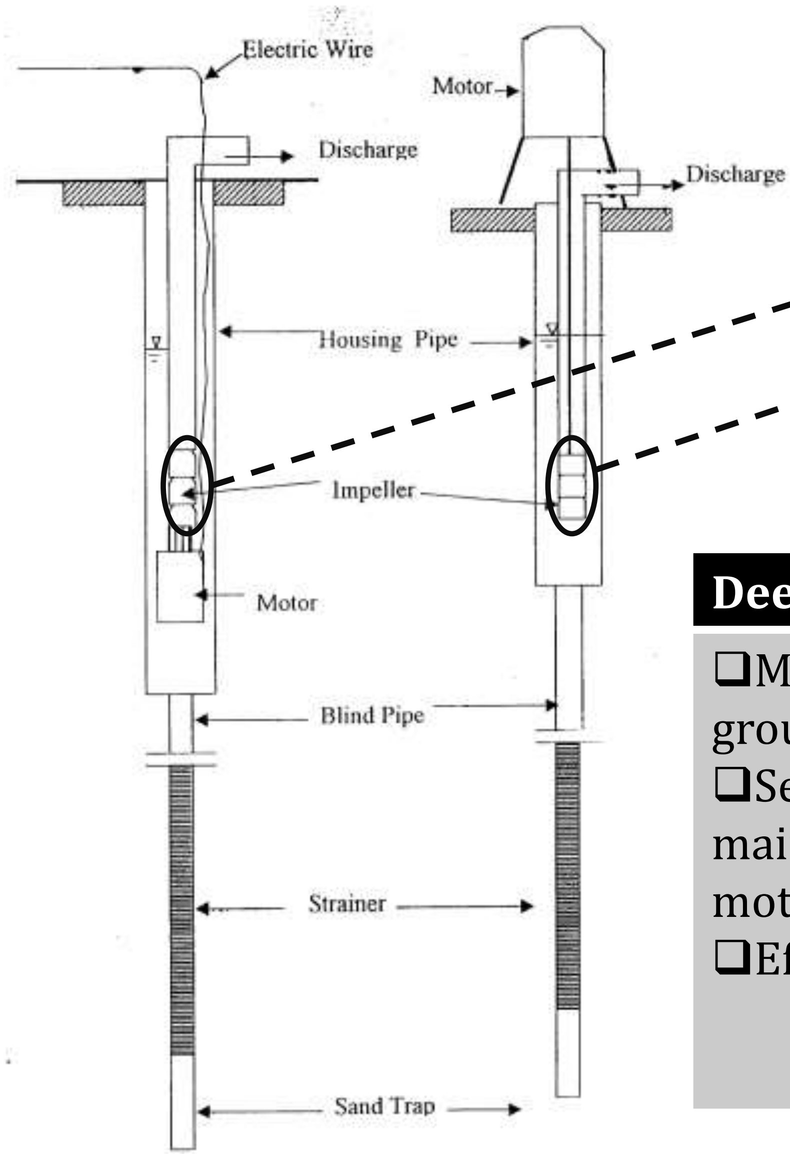
Both forward and return stroke discharges water

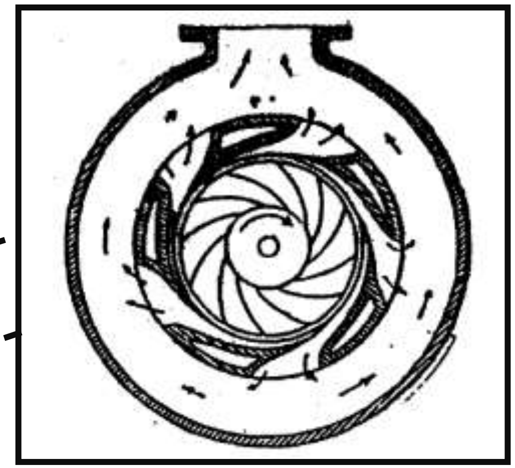
(c) Rotary pump

limited use in water works practice as water containing grit and suspended matter can damage the gears



Deep well turbine and submersible pumps





Deep well turbine	Submersible pump
❑Motor located at ground level ❑Service and maintenance of the motor convenient ❑Efficiency high	❑Motor is below the turbine bowls and submerged at all times ❑Entire motor pump assembly has to be lifted. ❑Efficiency comparatively less ❑Water can act as a coolant for the motor parts

Air Lift Pumps

Operating principle: that the mixture of air and water has a lower specific gravity than that of water alone.

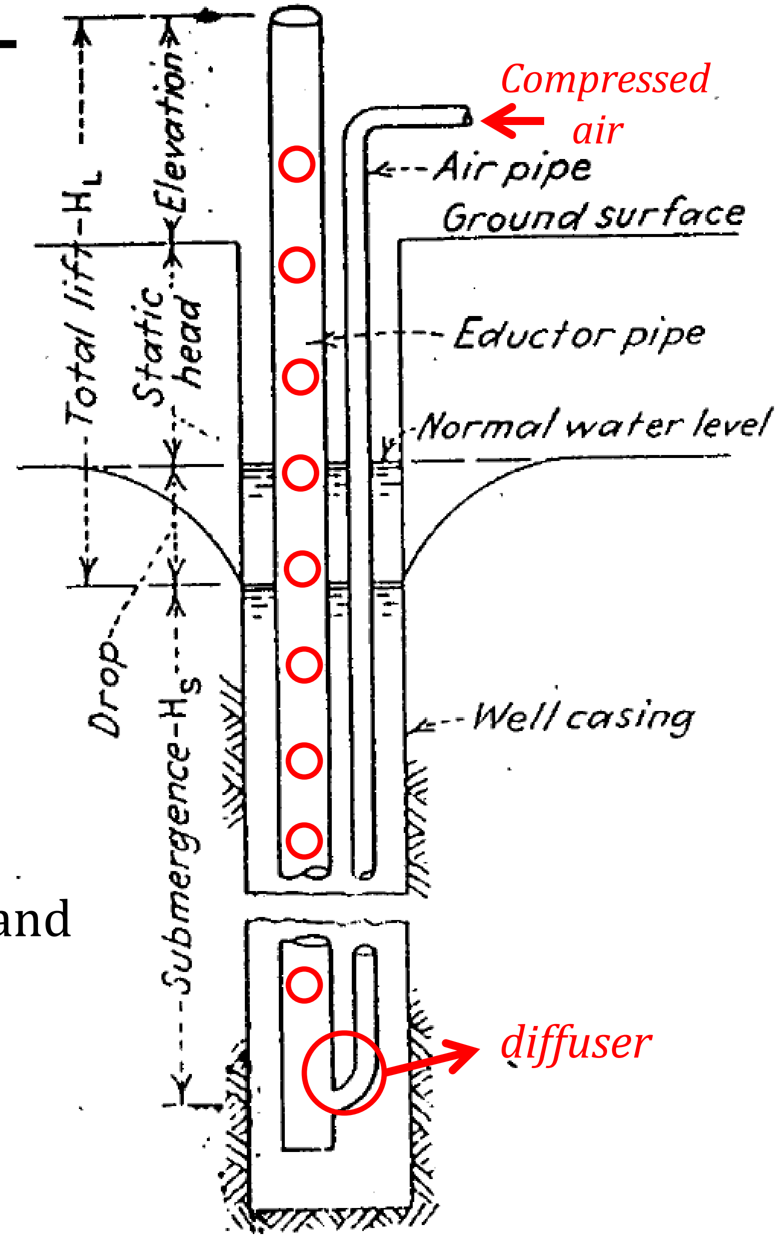
Effectiveness depends on the percentage submergence factor

$$\frac{H_S}{H_L + H_S} \times 100$$

(best efficiency at 70% while 25% required for the pump to operate)

Advantages: no submerged mechanical elements, suitable for crooked/dirty holes where mechanical parts can be abraded by sand particles

Disadvantages: high H_S requirement necessitates longer wells, low efficiency (20-45%), difficult flow control

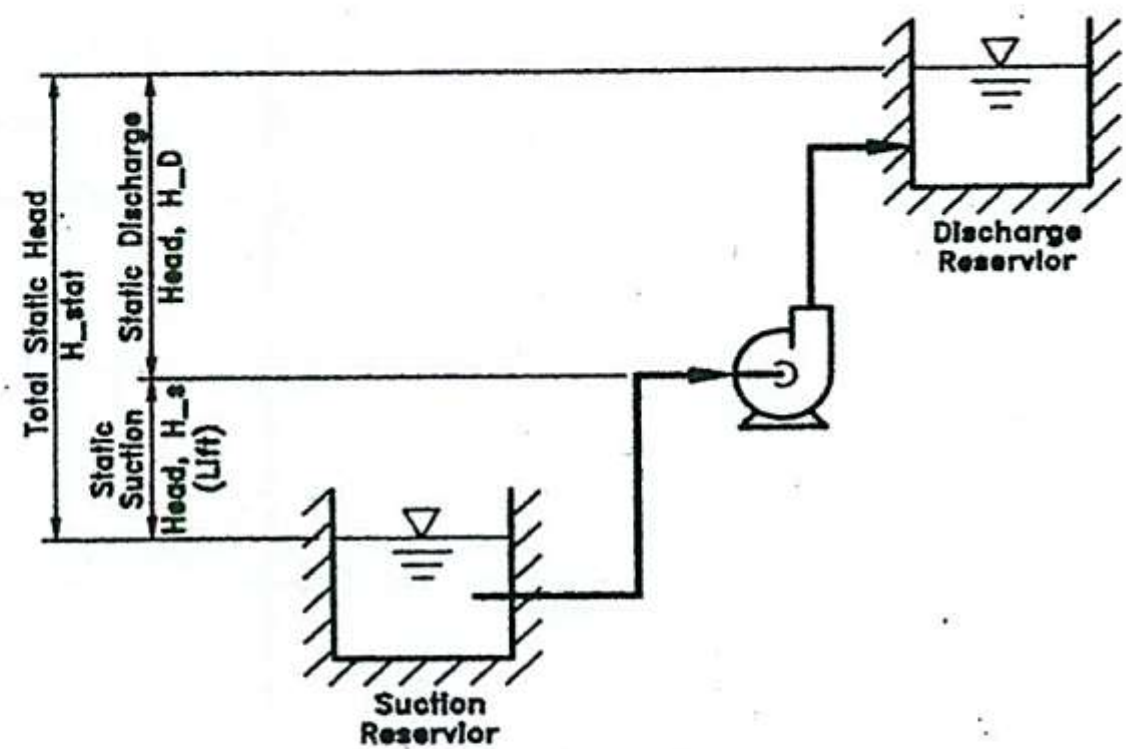


Head

Head describes hydraulic energy, expressed as the height of a column of liquid above a datum

For lift suction head,

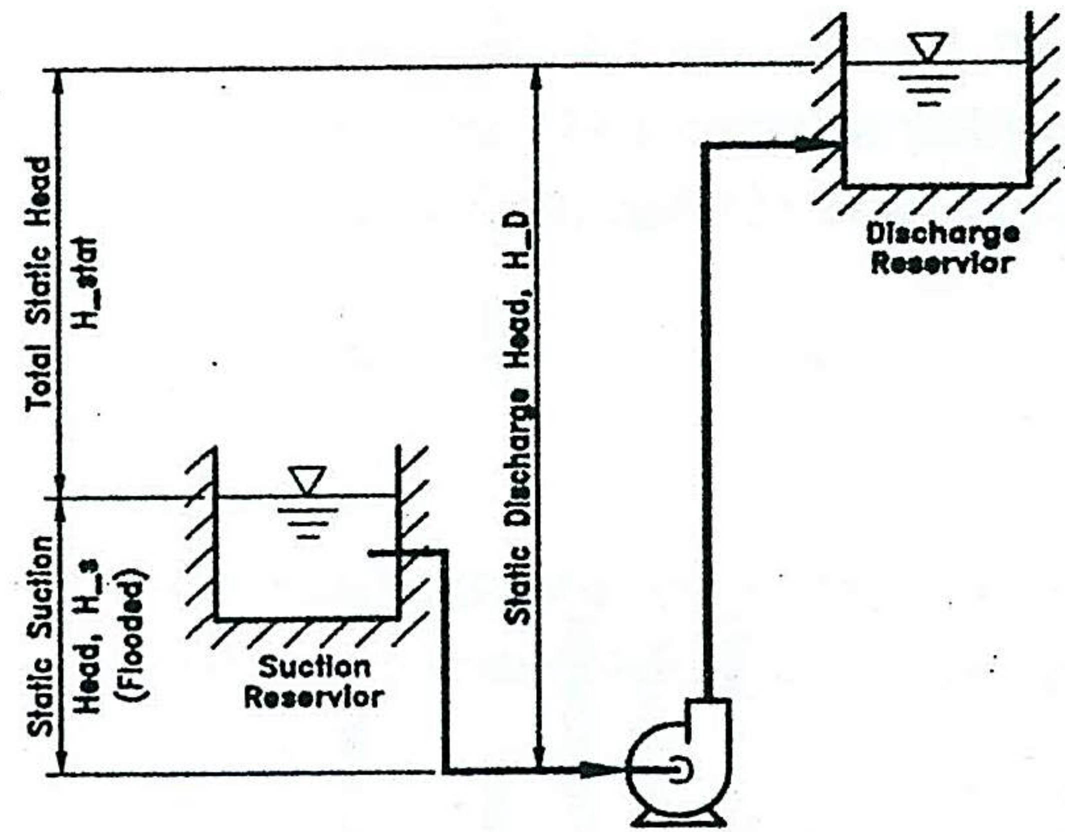
Static Head (H_{stat}) = Static Discharge head (H_D) + Static Suction head (H_S)



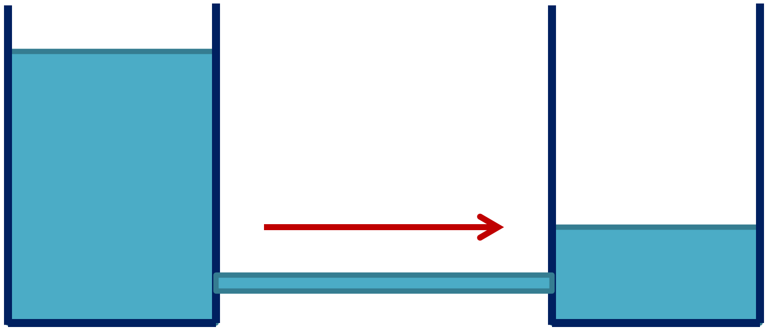
Head

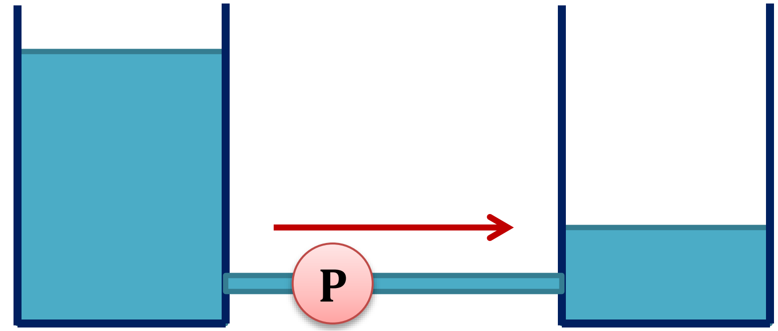
For flooded suction head,

Static Head (H_{stat}) = Static Discharge head (H_D) - Static Suction head (H_S)



Flow Through Pipes: The Energy Equation





$$\underbrace{\frac{p_1}{\gamma} + \alpha_1 \frac{\overline{V}_1^2}{2g} + z_1}_{H_{IN}} = \underbrace{\frac{p_2}{\gamma} + \alpha_2 \frac{\overline{V}_2^2}{2g} + z_2}_{H_{OUT}} + h_L$$

h_L: Viscous losses

$$\frac{p_1}{\gamma} + \alpha_1 \frac{\overline{V}_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \alpha_2 \frac{\overline{V}_2^2}{2g} + z_2 + h_L$$

h_p: Pump head

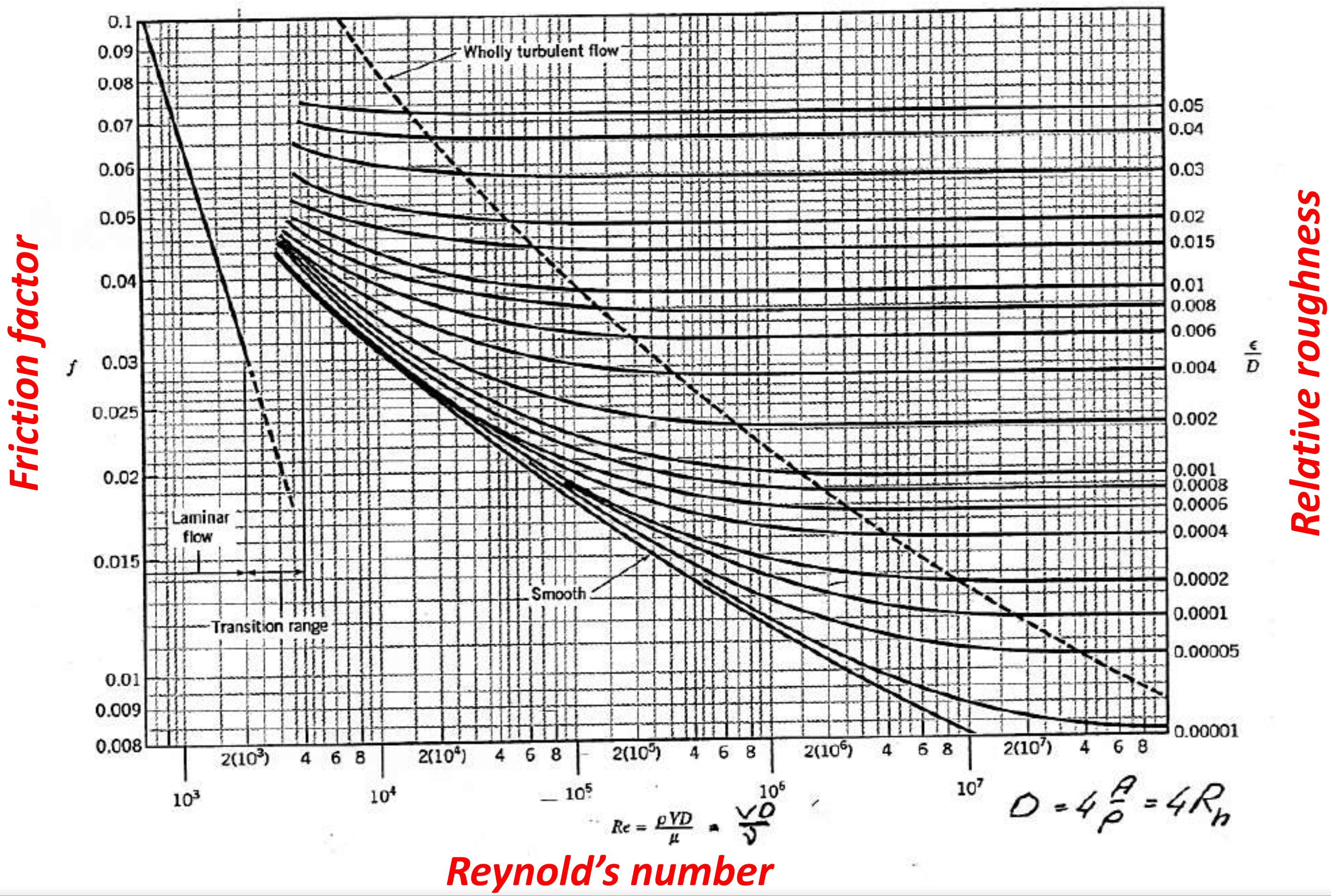
h_L = minor losses (due to entry, exit, bends, expansion etc) + Major losses (due to pipe friction)

[α = kinetic energy correction factor (=1 for turbulent flows), p/γ = pressure head, $V^2/2g$ = velocity head, z = elevation head, Q = flowrate, γ = unit weight of water]

Determining Head Loss Due to Friction

Head loss due to friction $= f\frac{L}{D}\frac{V^2}{2g}$ (Darcy-Weisbach equation)

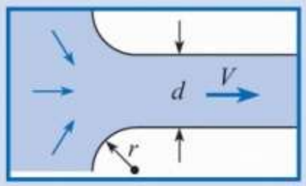
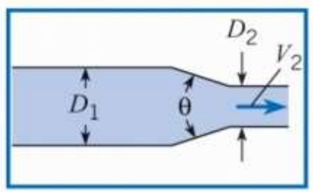
Moody's diagram



Determining Minor Losses

Minor losses can be estimated using coefficients from this table

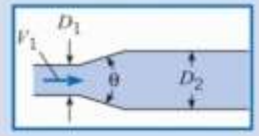
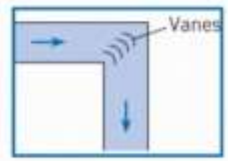
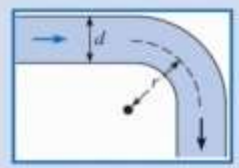
Table 10.5 LOSS COEFFICIENTS FOR VARIOUS TRANSITIONS AND FITTINGS

Description	Sketch	Additional Data		K
Pipe entrance		r/d		K_e
		0.0		0.50
		0.1		0.12
$h_L = K_e V^2/2g$		>0.2		0.03
Contraction			K_C	K_C
		D_2/D_1	$\theta = 60°$	$\theta = 180°$
$h_L = K_C V_2^2/2g$		0.00	0.08	0.50
		0.20	0.08	0.49
		0.40	0.07	0.42
		0.60	0.06	0.27
		0.80	0.06	0.20
		0.90	0.06	0.10

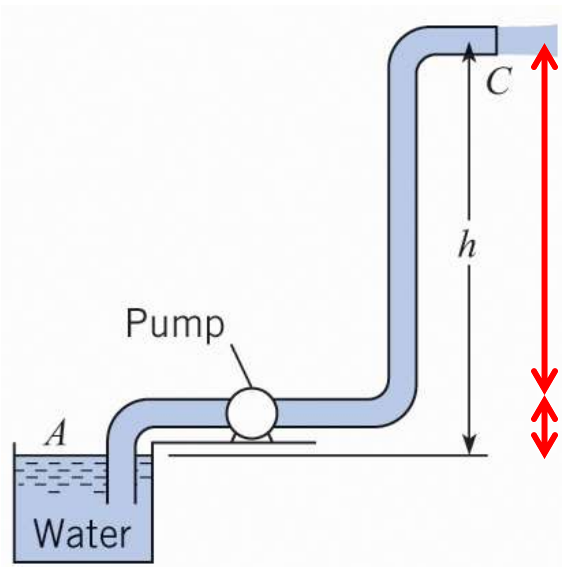
Reference: Table 10.5 of Crowe et al "Engineering Fluid Mechanics" (Ninth Edition)

Determining Minor Losses

Reference: Table 10.5 of Crowe et al "Engineering Fluid Mechanics" (Ninth Edition)

Description	Sketch	Additional Data		K
Expansion		D_1/D_2	K_E θ = 20°	K_E θ = 180°
$h_L = K_E V_1^2/2g$		0.00		1.00
		0.20	0.30	0.87
		0.40	0.25	0.70
		0.60	0.15	0.41
		0.80	0.10	0.15
90° miter bend		Without vanes	$K_b = 1.1$	
		With vanes	$K_b = 0.2$	
90° smooth bend		r/d		
		1	$K_b = 0.35$	
		2	0.19	
		4	0.16	
		6	0.21	
		8	0.28	
		10	0.32	
Threaded pipe fittings	Globe valve—wide open			$K_v = 10.0$
	Angle valve—wide open			$K_v = 5.0$
	Gate valve—wide open			$K_v = 0.2$
	Gate valve—half open			$K_v = 5.6$
	Return bend			$K_b = 2.2$
	Tee			
	Straight-through flow			$K_t = 0.4$
	Side-outlet flow			$K_t = 1.8$
	90° elbow			$K_b = 0.9$
	45° elbow			$K_b = 0.4$

Examples: Pump Head (Total Dynamic Head)



Discharge Head

Suction Head

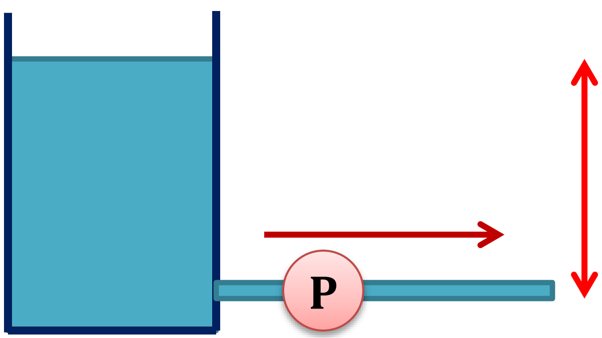
$$\frac{p_1}{\gamma} + \alpha_1 \frac{\bar{V}_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \alpha_2 \frac{\bar{V}_2^2}{2g} + z_2 + h_L$$

0 0 0 0 $V^2/2g$ h

$$h_p = h + \frac{V^2}{2g} + h_L$$

(Discharge + suction) head — Static Head

Losses due friction and minor losses



Static Head, h

$$h_p = -h + \frac{V^2}{2g} + h_L$$

Total head negative (for flooded suction head)

Power and Efficiency

Power produced by a pump (water power) is given by:

$$P_W = \gamma h_p Q$$

$$P_W = \frac{h_p Q}{3960}$$ P_W in horsepower, h_p in ft and Q in gpm

$$P_W = \frac{\gamma h_p Q}{75}$$ P_W in horsepower, h_p in m and Q in m^3/s and γ in kg/m^3

Input power (also called Break Power), P_P is related by the pump efficiency, E

$$E = \frac{P_W}{P_P} \times 100$$

Week-(05)

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Net Positive Suction Head (NPSH)

NPSH: the absolute pressure of the fluid at the pump centerline or impeller eye as it enters the pump suction

NPSH required: absolute fluid pressure required by the pump for smooth, efficient operation (determined experimentally by the manufacturer)

NPSH available: depends on the head and layout of pump suction piping:

$$NPSH_{av} = H_{abs} + H_S - h_L - H_{vp}$$

Absolute pressure on the surface of the liquid in the suction well (atm. Pressure)

Suction head at the pump suction

Vapor pressure of fluid

Net Positive Suction Head (NPSH)

NPSH available > NPSH required (recommended)

If NPSH available ≈ NPSH required, adjustments need to be made:

- ❑ Raise water surface level in the suction well
- ❑ Lower pump centerline elevation
- ❑ Reduce head loss by increasing suction piping size
- ❑ Select different model or type of pump

Cavitation

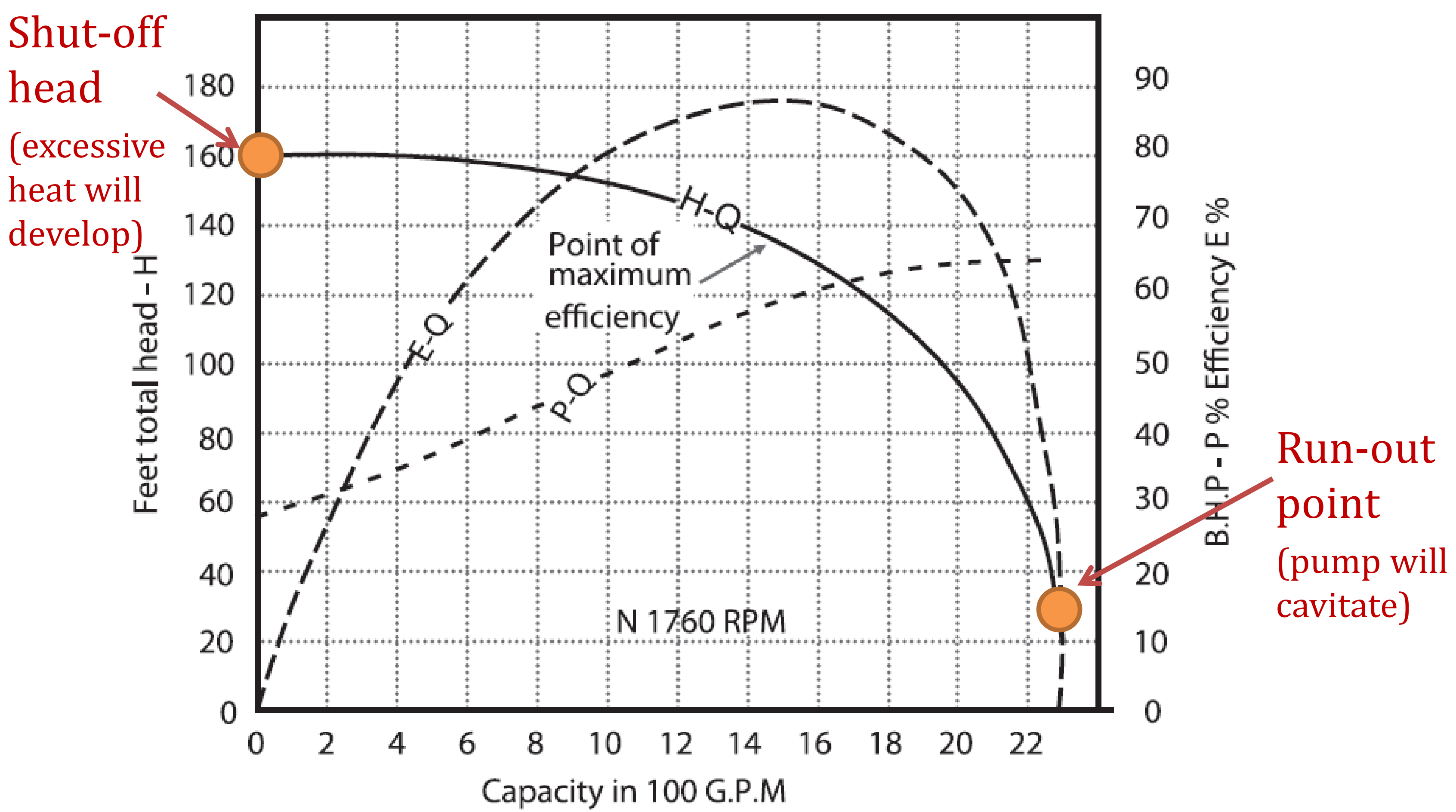
A phenomenon when absolute pressure of a fluid reaches the <u>fluid vapor pressure </u>(cavities formed, fluid literally boils with a distinctive rattling noise, as a result severe pitting of the metallic surfaces may occur)

Cavitation may be corrected by making the following adjustments:

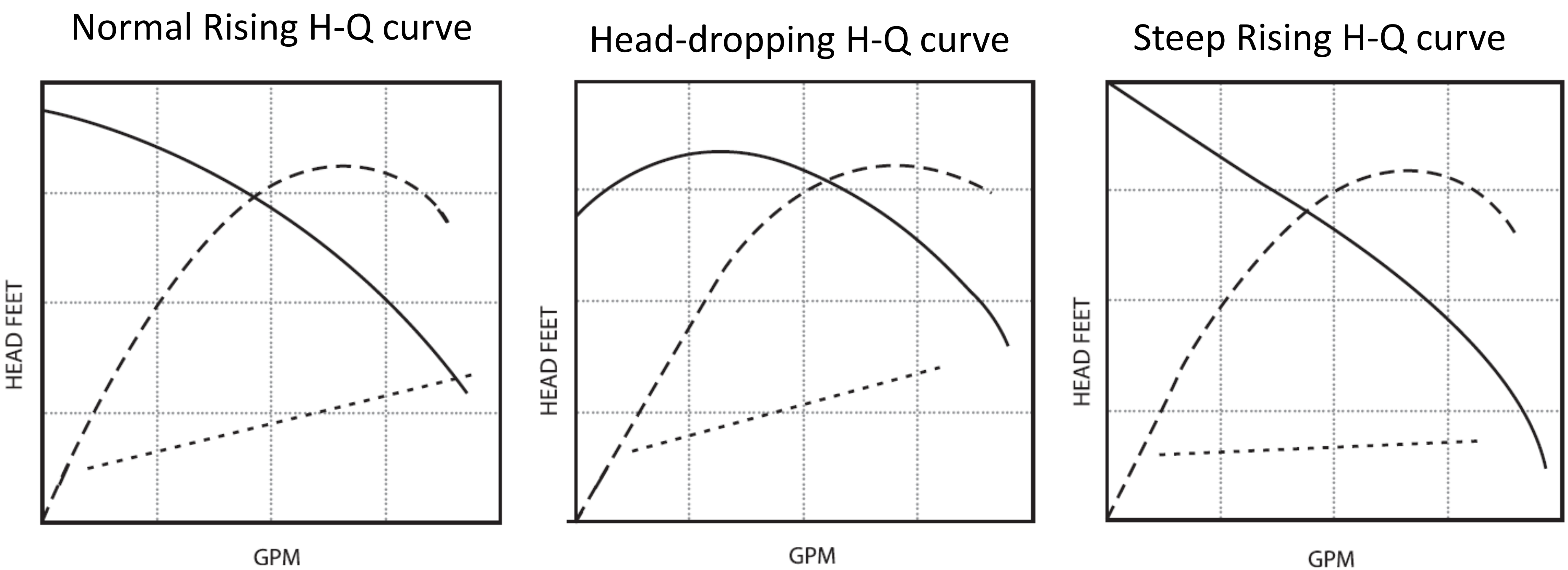
- ❑ Increase the diameter of the pump-suction piping
- ❑ Decrease the pump speed
- ❑ Increase the static head on suction side
- ❑ Decrease the flow rate

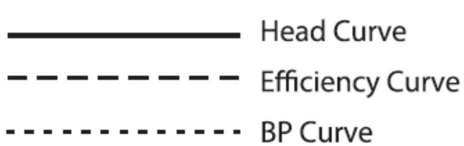
Pump Characteristic Curves

A series of graphs representing the performance of a pump under various conditions



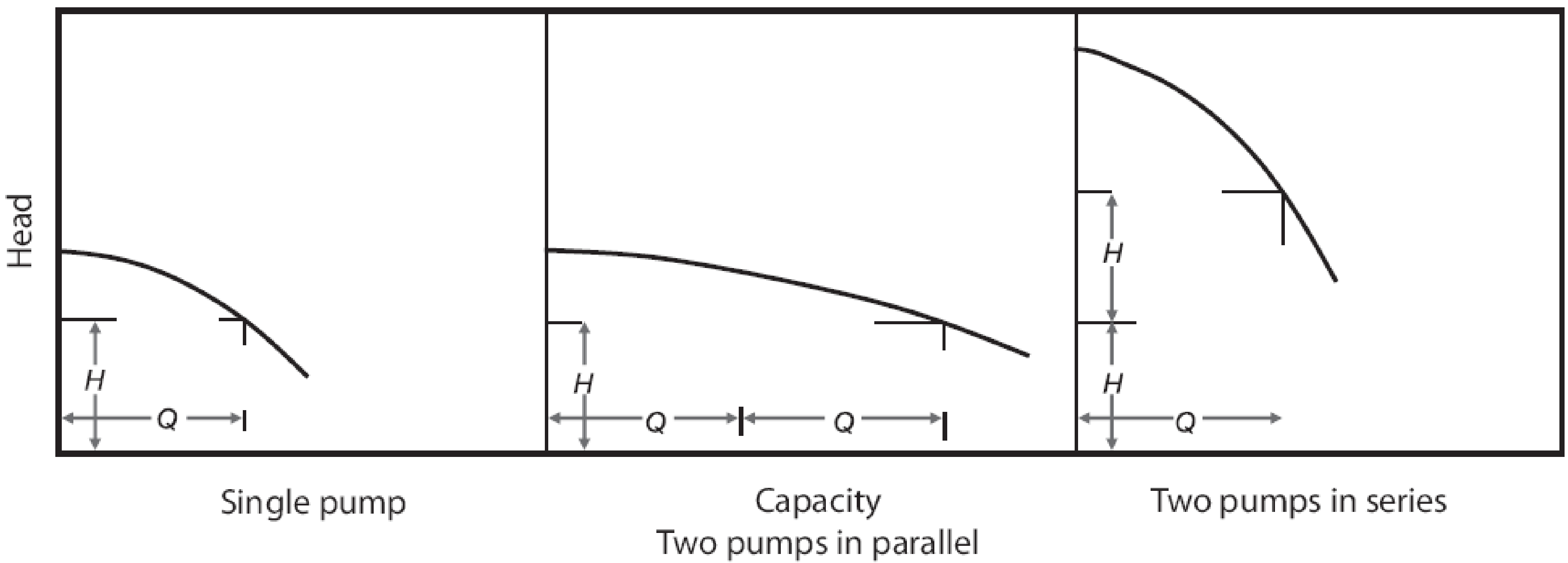
Different types of H-Q curves





“Normal-rising” and “Steep-rising” H-Q pumps will perform better in parallel and will have relatively small capacity change with pressure changes

Pumps in Combination



Pumps in parallel: pump discharges are added for respective heads

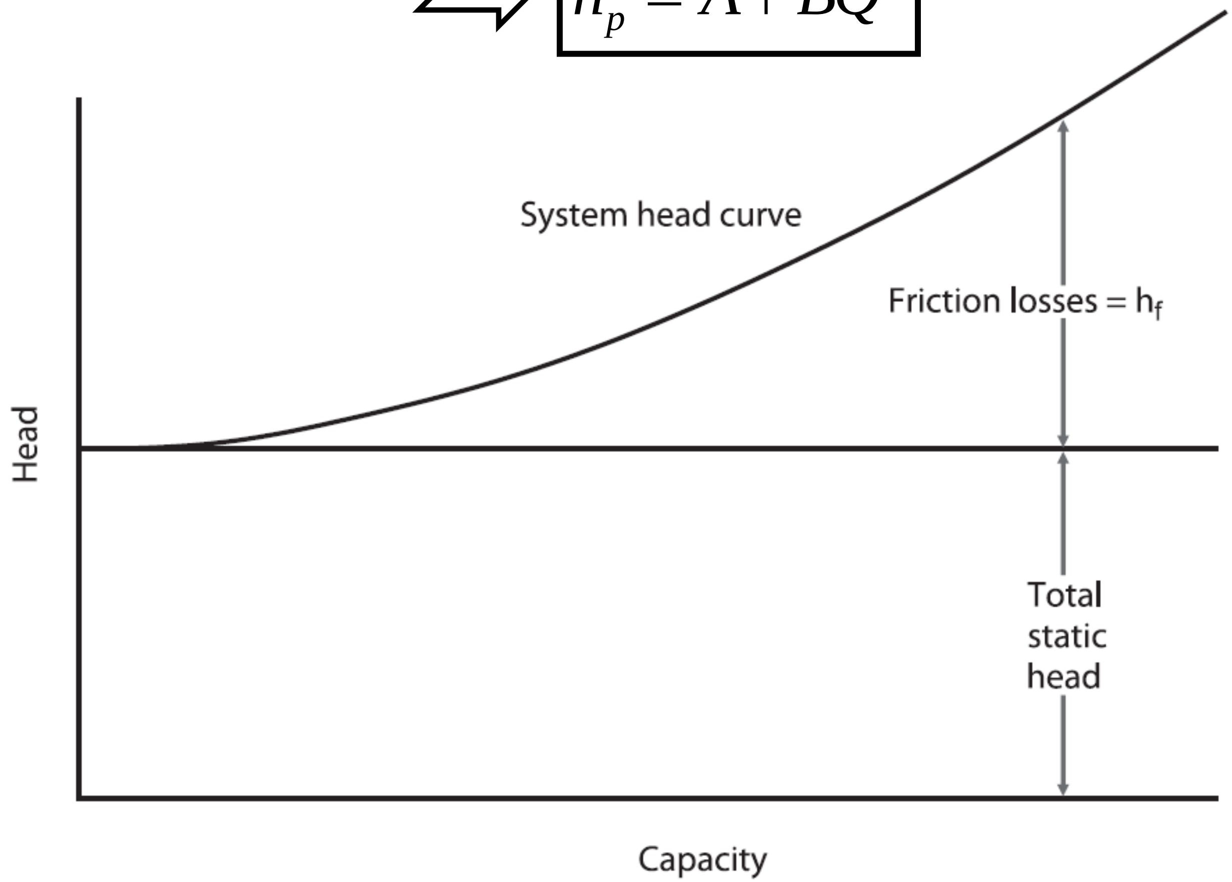
Pumps in series: pump heads are added for a particular capacity

The System Curve

Using the Energy equation

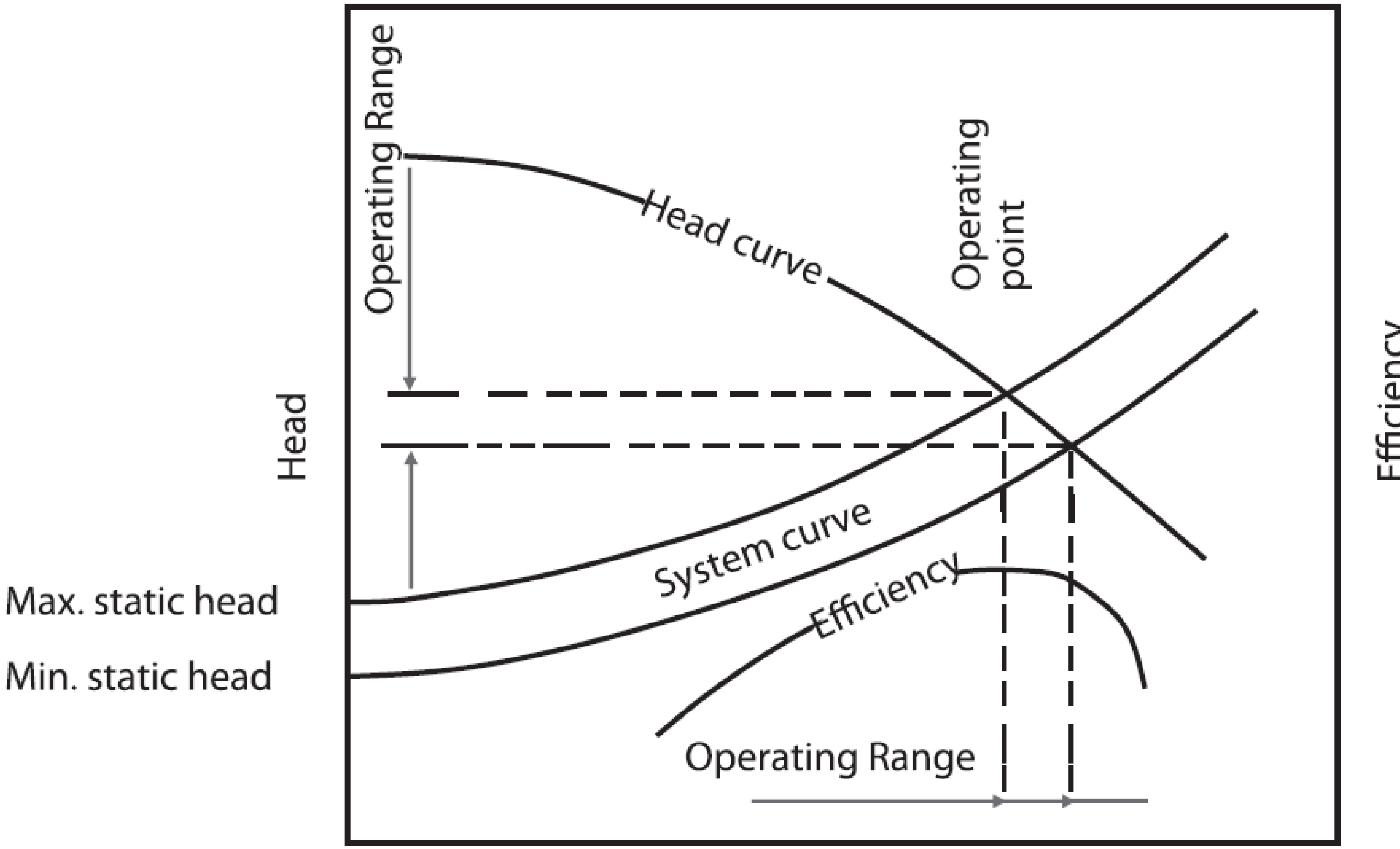
$$\frac{p_1}{\gamma}+\alpha_1\frac{\overline{V}_1^2}{2g}+z_1+h_p=\frac{p_2}{\gamma}+\alpha_2\frac{\overline{V}_2^2}{2g}+z_2+h_L$$

$$\Rightarrow \boxed{h_p = A + BQ^2}$$



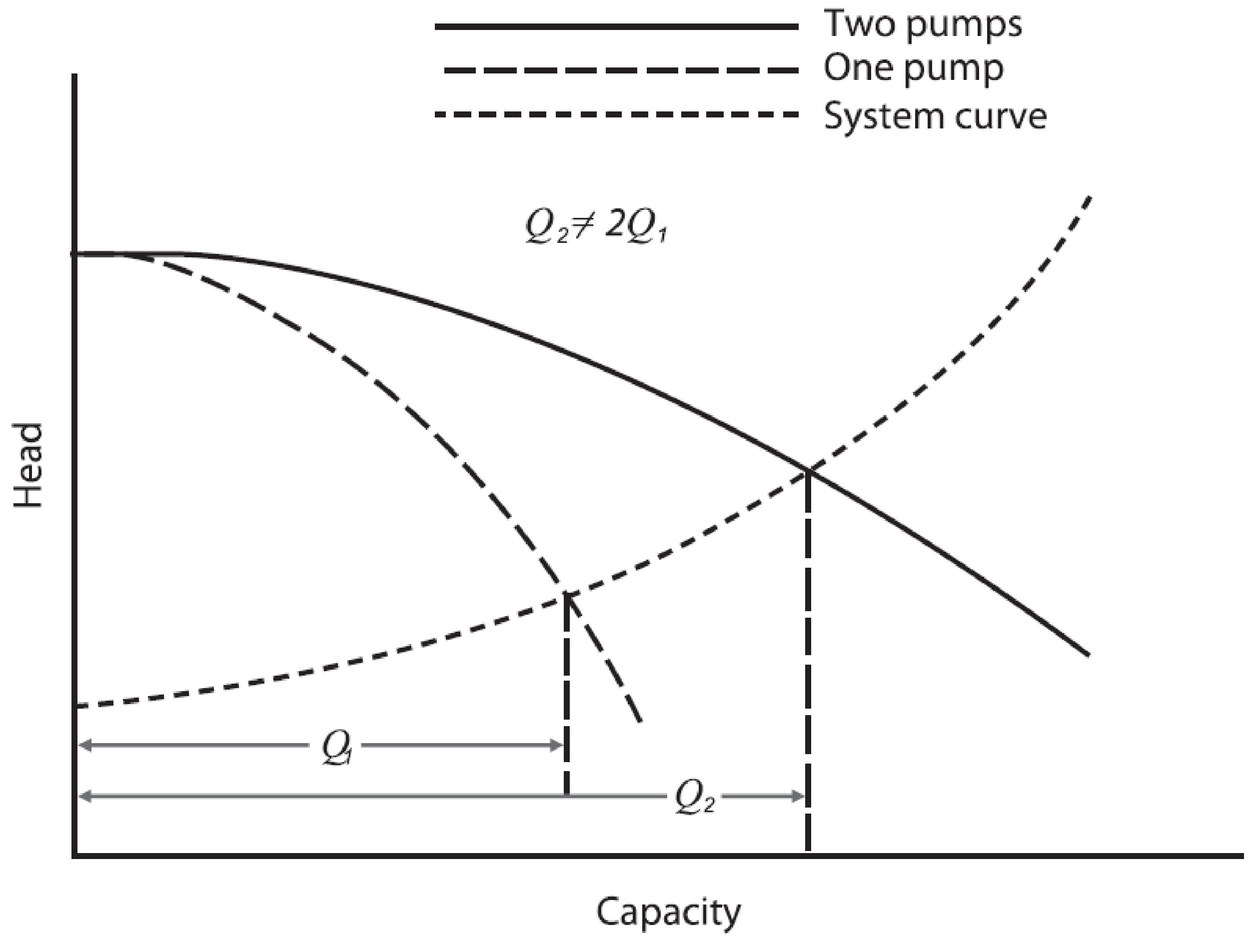
The Operating Point

A pump that has an operating point at or near its peak efficiency should be selected.



Pumps in Parallel

The added capacity for two pumps in parallel generates more friction loss and the operating capacity is not doubled.



Pump Selection Considerations

System head capacity curve: should operate smoothly over variable static-head conditions

Suction Head: NPSH required should be at least 1 m less than NPSH available.

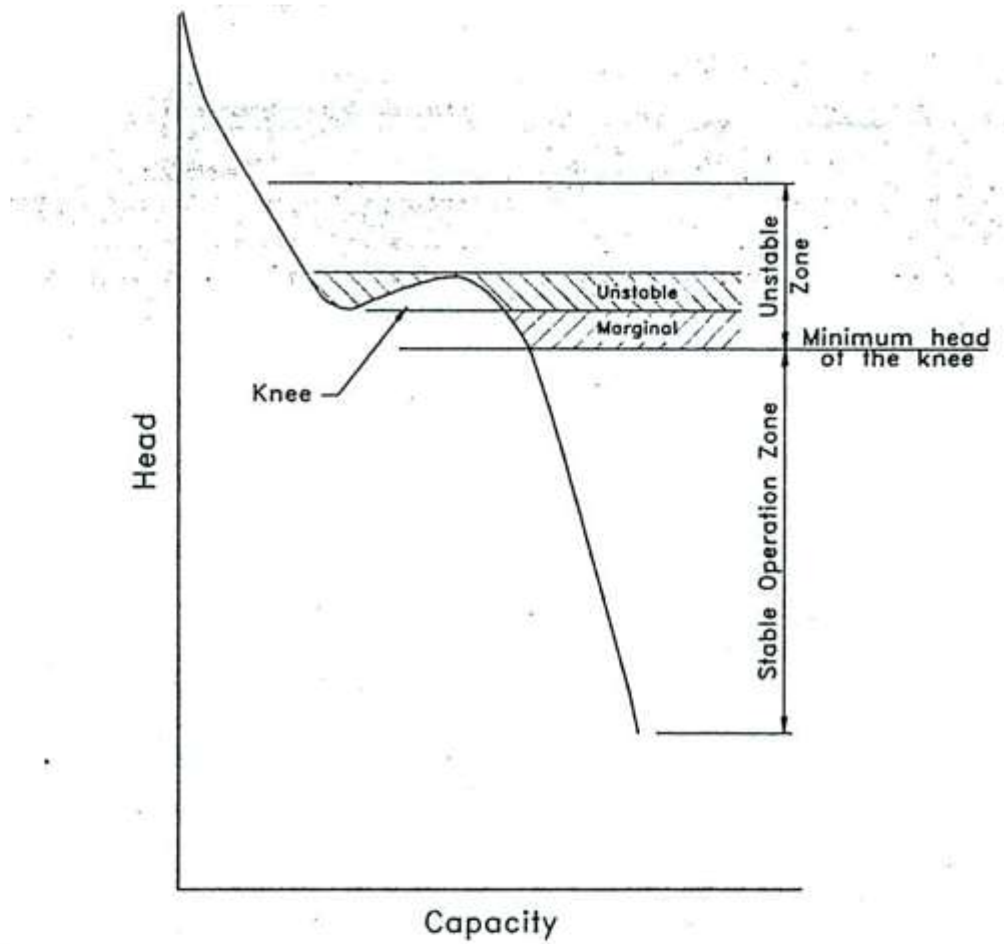
Efficiency: Should be selected to operate near peak efficiency at normal operating conditions

Shut-off and run-out: should be selected to operate in the middle of the head-capacity curve. Operating near the shut-off and run-out heads can damage the pump

Solids: water supply pumps are typically designed to pass only very small solids (screens must to be used to remove solids)

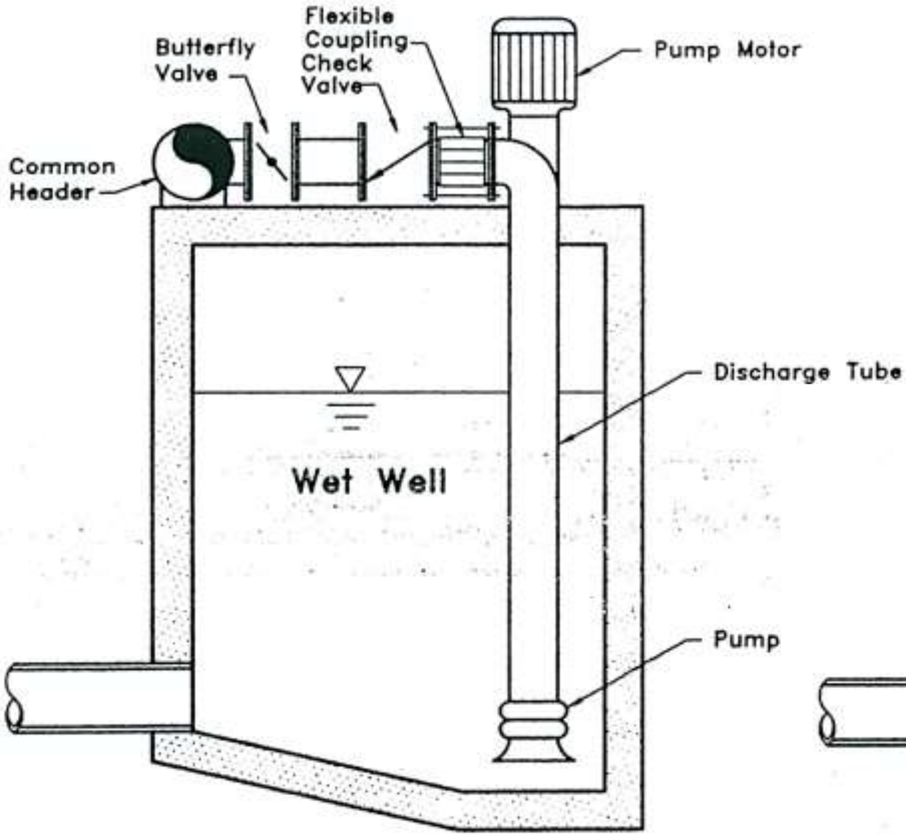
Pump Selection Considerations

Unstable operation: Pumps should be operated at a head that is lower than the minimum head of the knee (inflection point in the H-Q curve)

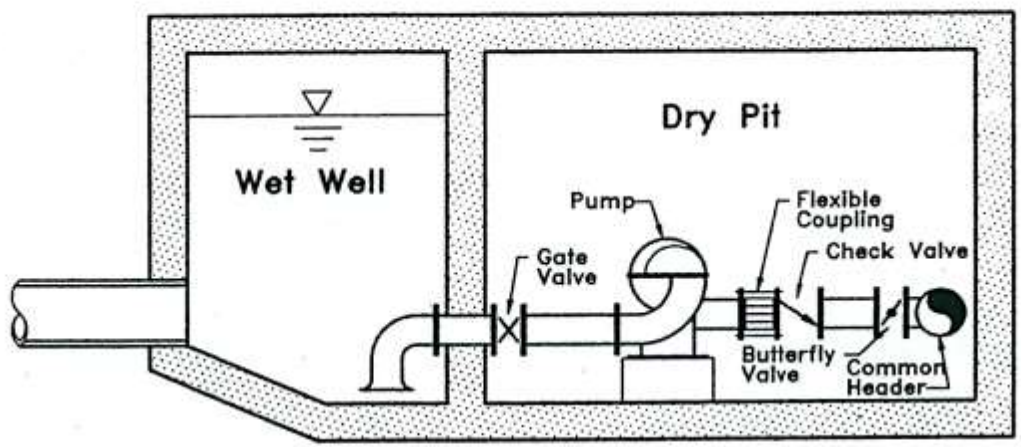


Pump Stations

Structures that house pumps, piping, equipment and chemicals.

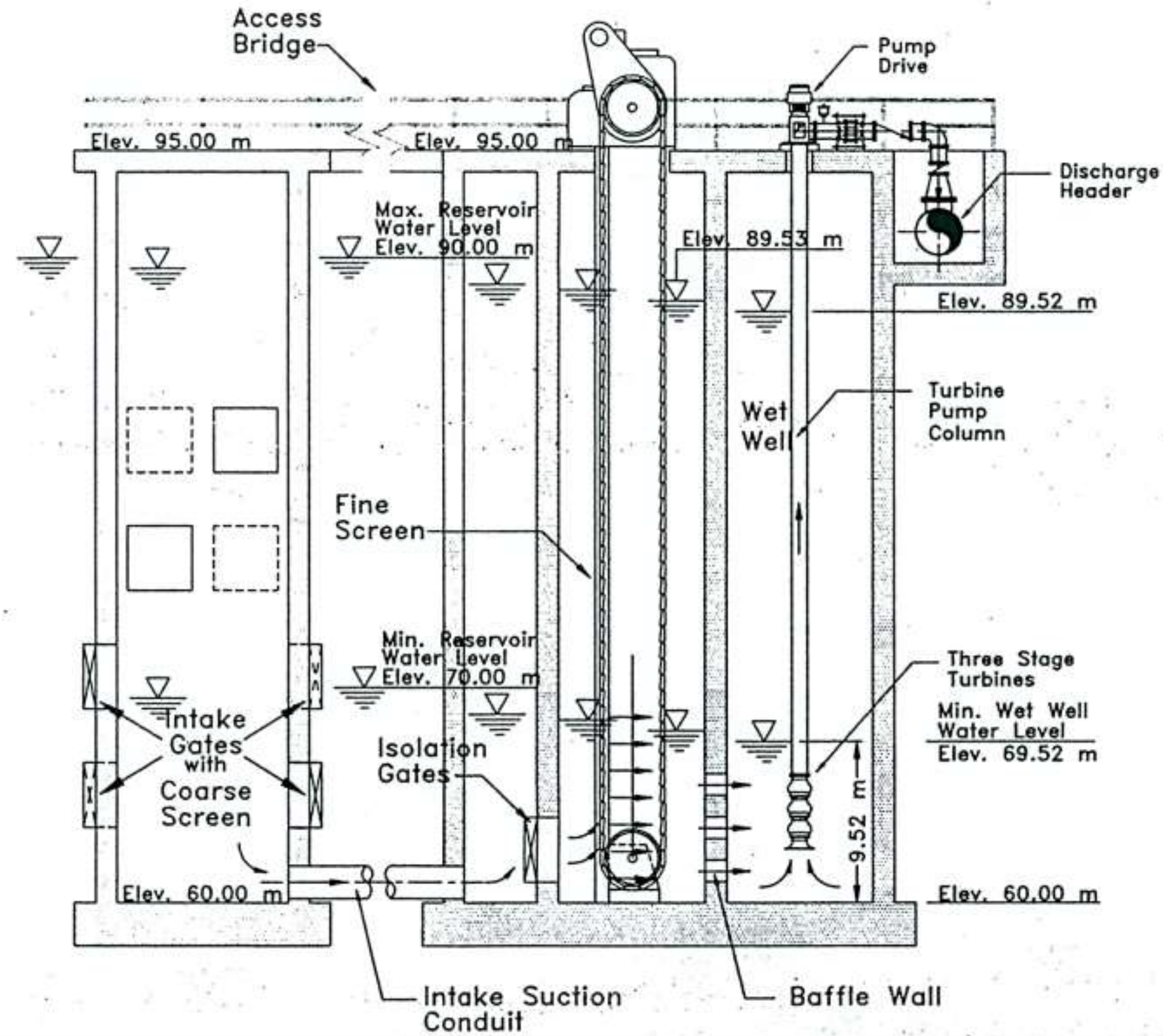


Wet-pit pumping station



Dry-pit pumping station

Intake Structure and Pumping Station



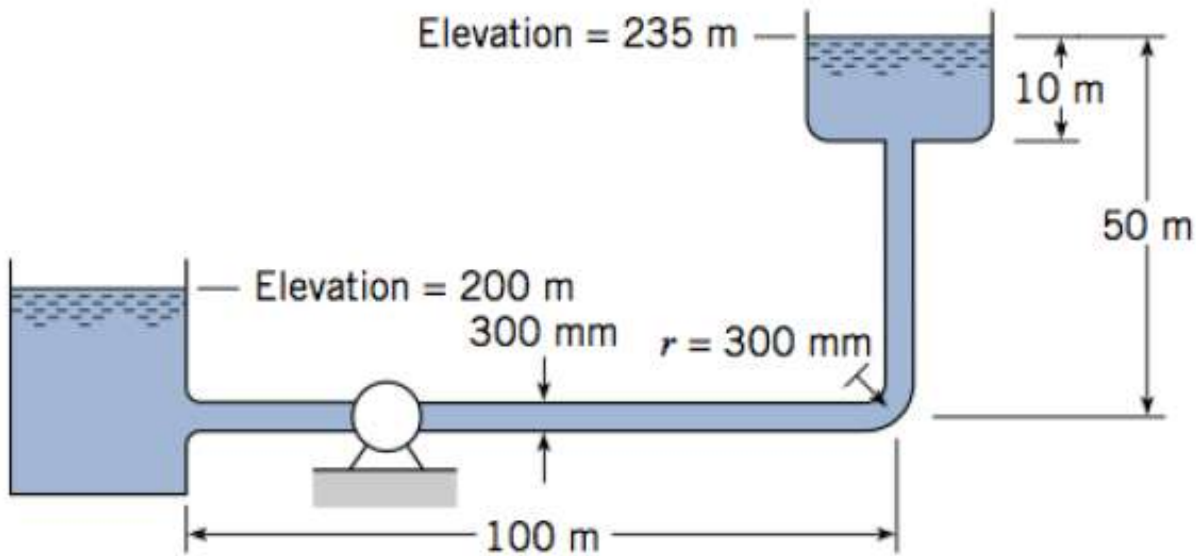
Example Problem 1

Design the transmission main and the pumping unit from the following data:

- Water supply rate = 40 gpcd
- Estimated population = 85000
- Ground R.L. at pump house = 102.50 ft
- Treatment plant R.L. = 193.00 ft
- Velocity through the pipes = 8 fps
- Pumping time = 10 hours daily
- Total length of pipe = 3500 ft
- Friction factor = 0.01
- Efficiency of pump = 65%

Example Problem 2

What power must be supplied by the pump to the flow if water ($\nu = 10^{-6}$ m^2/s) is pumped through the 300 mm steel pipe (ε = 0.046 mm) from the lower tank to the upper one at a rate of 0.314 m^3/s?



[Assume: pipe entrance is well rounded i.e. r/D>0.2

$K_{entrance} = 0.03$, $K_{bend} = 0.35$, $K_{exit} = 1$]

Example Problem 3

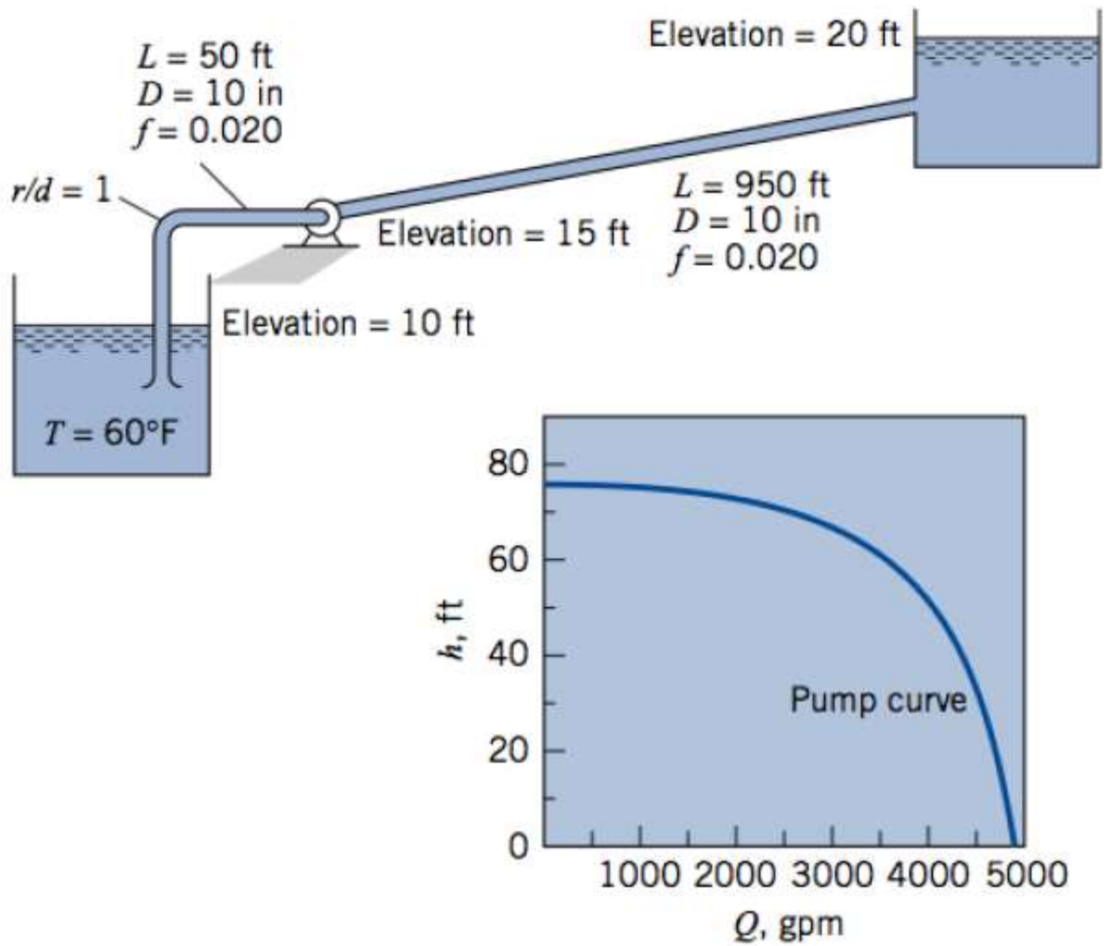
A pump that has the characteristic curve shown in the graph is to be installed as shown in figure. What will be the discharge of water in the system?

[Assume: pipe entrance is well rounded i.e. r/D>0.2

$K_{entrance}$ = 0.03,

K_{bend} = 0.35,

K_{exit} = 1]



Reading Materials for this Lecture

Water Supply Engineering (by M. A. Aziz)

Chapter 5: Water and Environmental Engineering (by H. Rahman and A. A. Muyeed)

Chapter 7: Water Works Engineering (by Qasim and co-authors)
[<u>photocopy of the chapter provided in class</u>]

Week-(06)

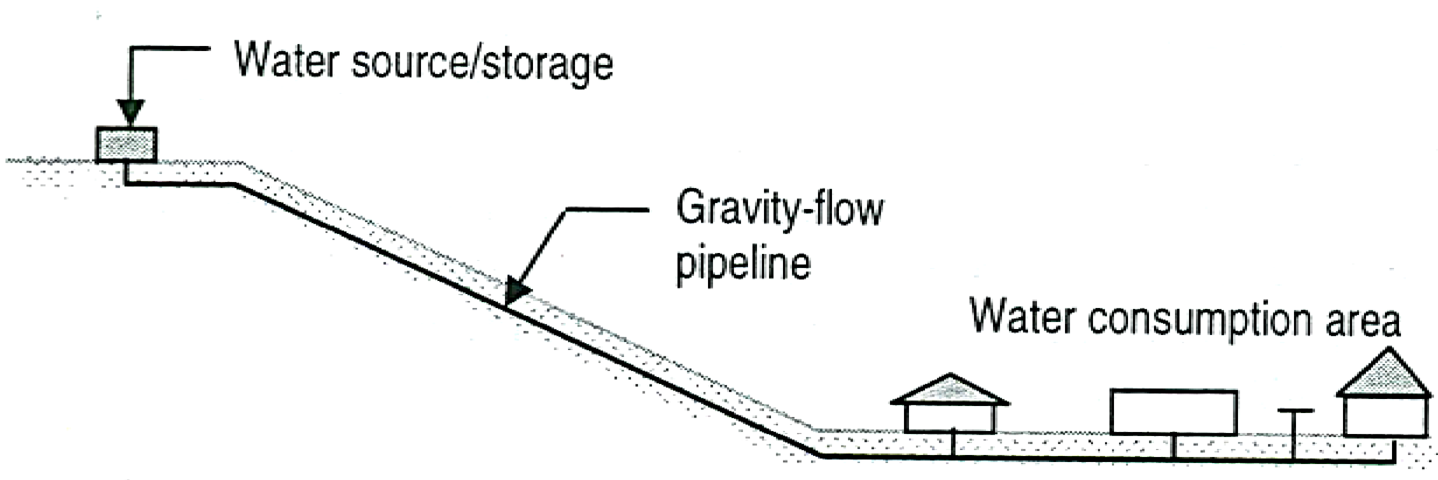
MD Ehasan Kabir

Purpose of the Water Distribution System

- To make water available in close proximity to the consumers
- To supply water in adequate quantities according to the demand of the consumers
- To supply water with adequate pressure
- To regulate water supply as per requirement

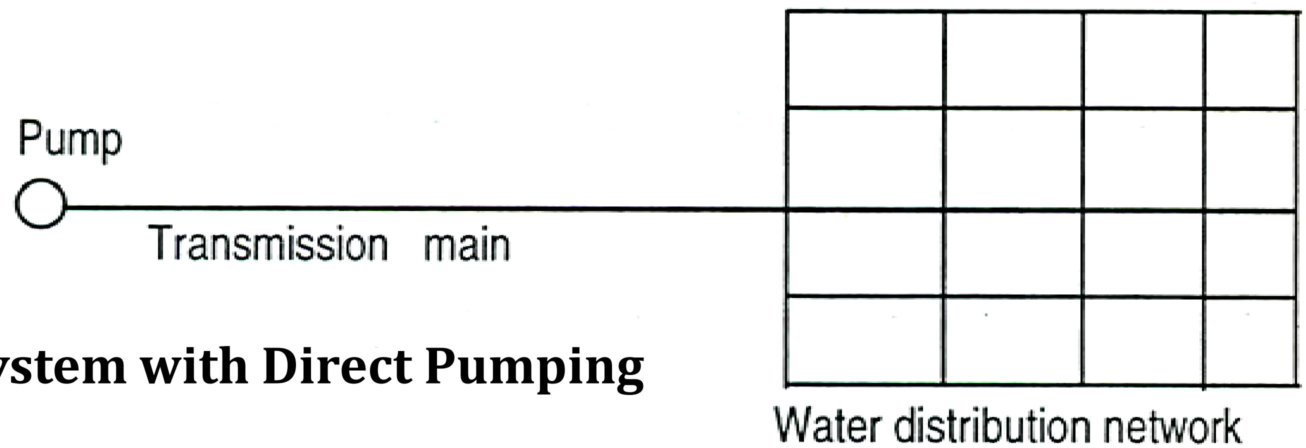
Classification of T&D System

1) Gravity flow system
2) System with Direct Pumping
3) System with pumping and storage

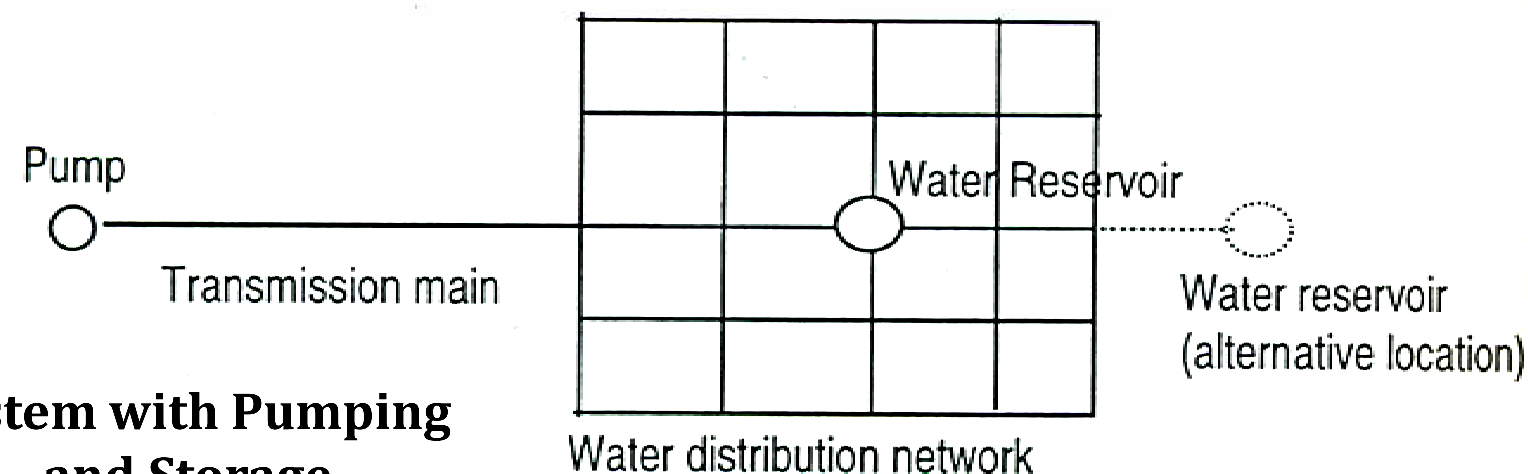


Gravity flow system

Classification of T&D System



System with Direct Pumping



System with Pumping and Storage

Gravity Flow System

Advantages

1) Requires no energy to operate
2) No pumps, very few moving parts
3) Construction, operation and maintenance simple

Disadvantages

1) Not suitable for flat countries where an elevated water source is unavailable
2) Water loss by leakage and wastage is comparatively higher as the system remains under constant pressure

Direct Pumping System

Advantages

1) Water can be pumped only when required
2) Low water loss due to system leakage

Disadvantages

1) Power failure means breakdown of the system
2) Direct pumping at a uniform rate is not able to meet varying water demand and maintain required pressure under varying rates of consumption
3) Maintenance and operation costs are high
4) Inflow of water through leaks cause contamination during non-pumping hours

Pumping with Storage System

Advantages

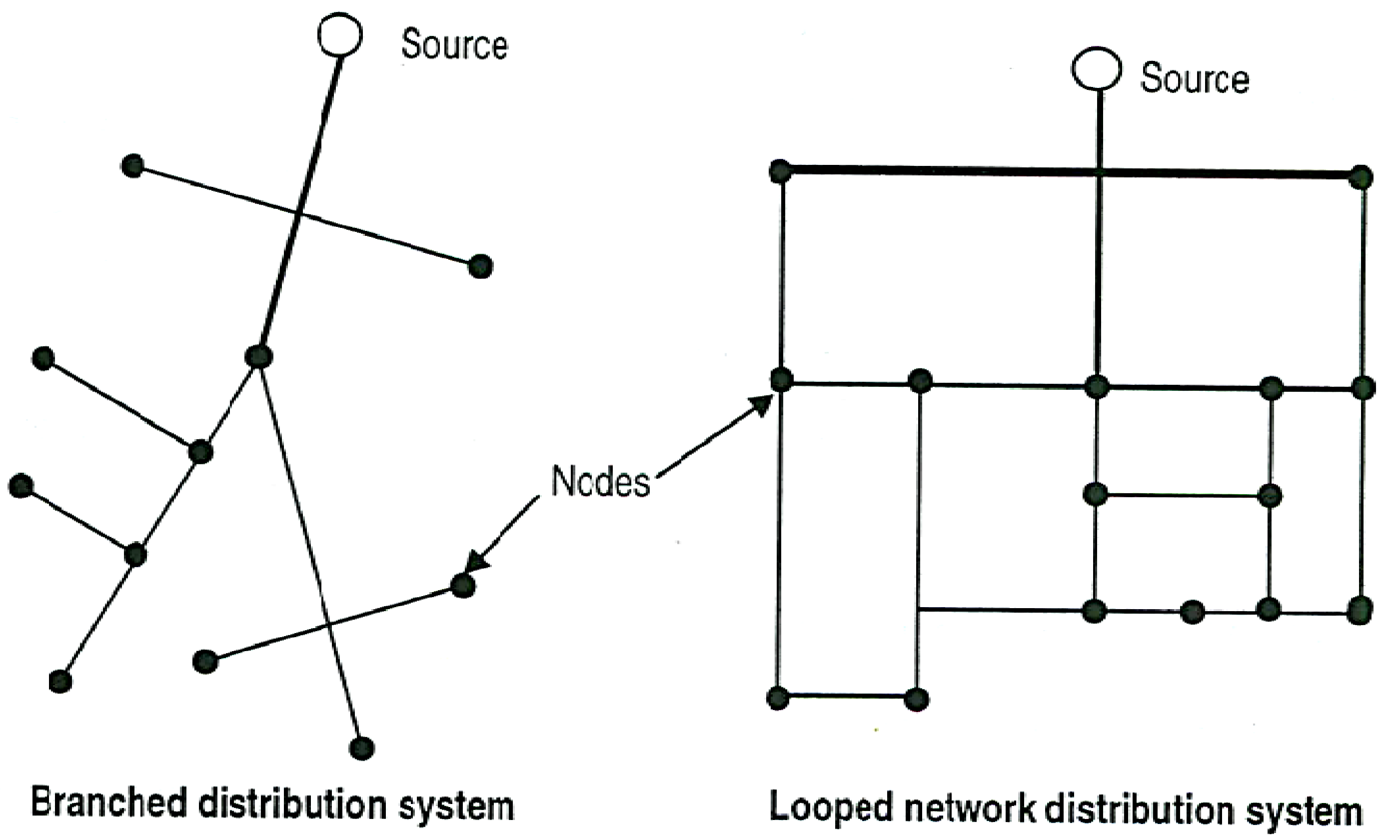
1) System more reliable and can cope with fluctuation of water demand
2) The pumps can be operated at rated capacity resulting in higher efficiency and economy in operation
3) Reasonable pressure can be maintained with varying water demand and there is no possibility of inflow of polluted water in the system

Disadvantages

1) Relatively higher initial cost
2) Comparatively higher loss due to leakage and wastage

Distribution Network

1) Branched Distribution Network
2) Looped Distribution Network



Branched Network

Advantages

1) Relatively cheap as length of pipe required is less
2) Easy for hydraulic design and determining discharge and pressure at any point
3) Can be easily expanded to provide coverage to newly developed areas

Disadvantages

1) Stagnant water (i.e. at dead-ends) promotes sedimentation and water contamination
2) Frequent blow-off or flushing is needed to keep the system clean
3) Repair work in mains and sub-mains cuts off water supply downstream

Looped Network

Advantages

1) No stagnation of water, consumption of water at any point activates flow in the whole network
2) Repair work does not disrupt continuity of water flow
3) Good control over flow of water

Disadvantages

1) High initial cost
2) A large number of valves is needed if control of flow in the system is desired

Distribution System Design

Recall Hazen Williams Formula for circular pipes:

$$V = 0.55CD^{0.63}h_L^{0.54}$$ *(British Units)*

$$V = 3.7\times10^{-6}CD^{2.63}h_L^{0.54}$$ *(Q in litre/sec, D in mm, h_L in m/m)*

⇩

$$h_L = 1.39\times10^{6}Q^{1.85}D^{-4.87}$$ *(when C = 130)*

$$h_L = 1.59\times10^{6}Q^{1.85}D^{-4.87}$$ *(when C = 120)*

Design Procedure for Branched Network

1) Prepare layout of the pipes using the map of road networks
2) Determine peak flow at different points and thereby determine the quantity flowing through each section of the pipe. **Peak flow = average daily flow × peak factor**
3) Assume pipe sizes of all pipes in the network (to calculate pipe size the velocity may be assumed to be 1 m/s)
4) Calculate h_L (use Hazen Williams Formula) and total head loss (using total length of the pipe)
5) Determine the terminal pressure head taking into account the change in elevation of the pipe
6) In case of difference between the computed and permissible terminal pressure, revise the pipe size

Design Procedure for Looped Network

Requires trial and error solution

Principle:

- The flow entering a junction must be equal to the flow leaving it
- The algebraic sum of the pressure drop (head loss) around any closed loop must be zero

Hardy Cross developed a method of successive approximation in which the circuits are balanced, distribution of flow is determined and the above two conditions of flow are satisfied.

<u>A flow is assumed for each pipe, a correction to the flow is applied successively for each pipe loop until the correction is reduced to an acceptable value</u>

The correction, Δ in Hardy Cross Method

If assumed flow is Q_a and actual flow is Q, then the correction is Q - Q_a

$$Q = Q_a + \Delta$$

$$\Rightarrow \quad \sum k(Q_a + \Delta)^x = 0$$

$$h_L = H / L = 1.39 \times 10^6 Q^{1.85} D^{-4.87}$$

(when C = 130)

$$\Downarrow$$

$$H = kQ^x$$

(k is a constant depending on the length, diameter and roughness of the pipe as well as fluid property)

(x = 1.85 according to Hazen Williams formula)

The correction, Δ in Hardy Cross Method

Expanding the equation $\sum k\left(Q_a + \Delta\right)^x = 0$

$$\sum kQ_a{}^x + x\sum k\Delta Q_a{}^{x-1} + \left(\frac{x-1}{2}\right)\sum k\Delta^2 Q_a{}^{x-2} + \ldots\ldots = 0$$

Δ is small compared to Q, the third and all successive terms of the equation may be neglected

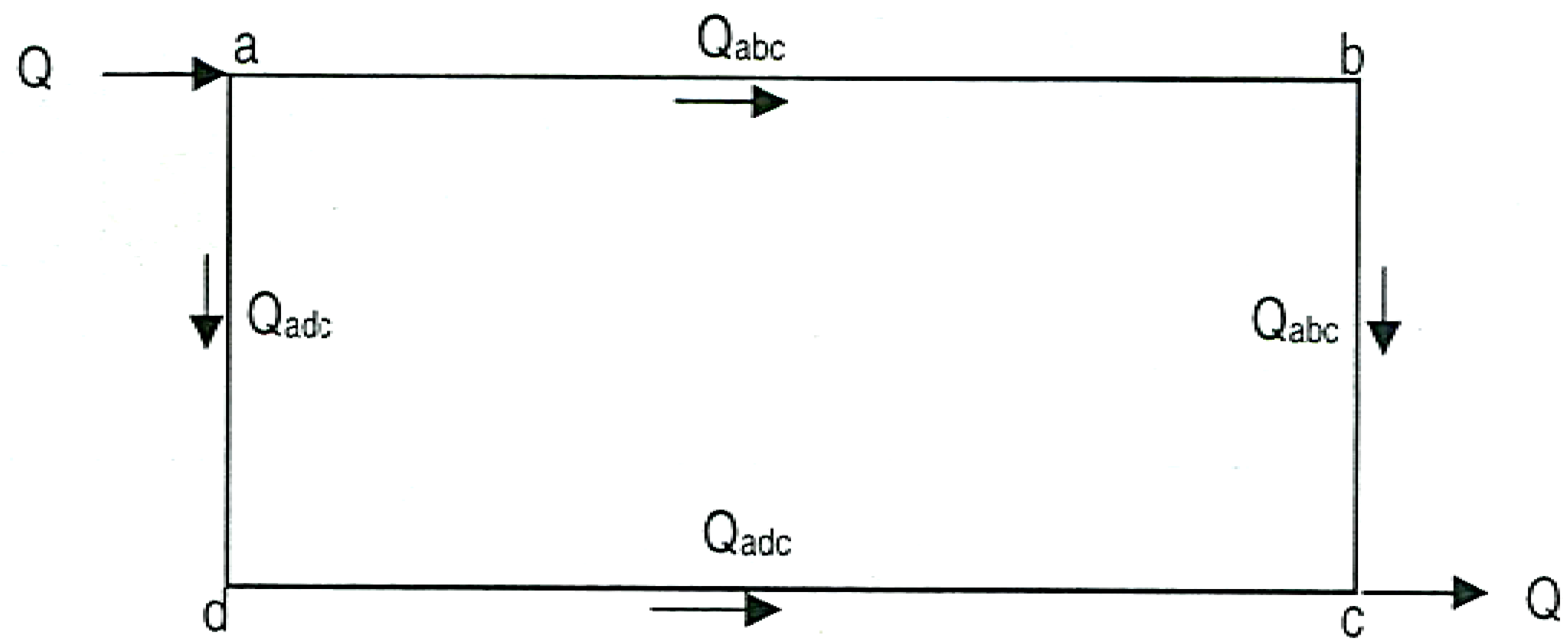
$$\sum kQ_a{}^x + x\sum k\Delta Q_a{}^{x-1} = 0$$

Solving for Δ:

$$\Delta = -\frac{\sum kQ_a{}^x}{x\sum k\Delta Q_a{}^{x-1}} \qquad \Delta = -\frac{\sum H}{x\sum H/Q_a}$$

The correction, Δ in Hardy Cross Method

$$\Delta = -\frac{(H_{ab} + H_{bc}) - (H_{ad} + H_{dc})}{x\left[(H_{ab} + H_{bc})/Q_{abc} + (H_{ad} + H_{dc})/Q_{adc}\right]}$$

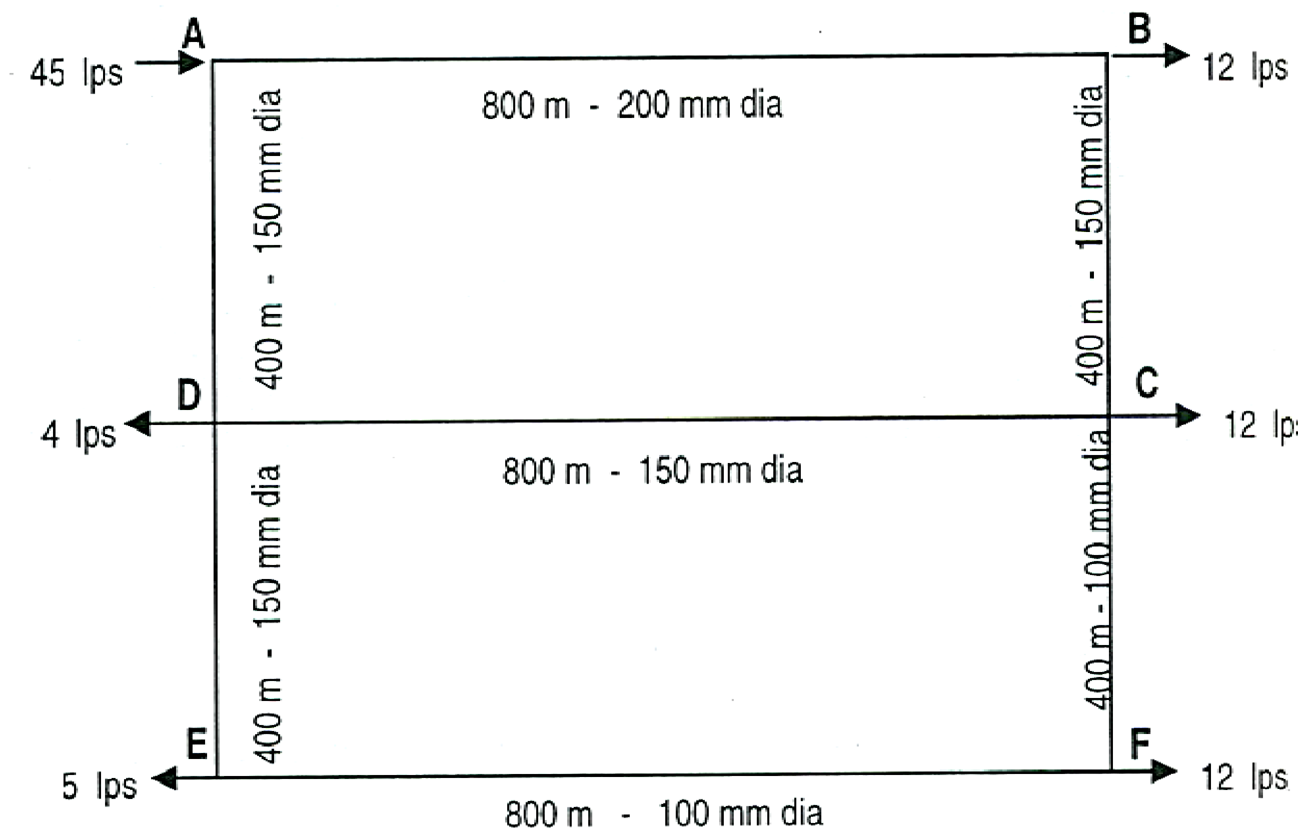


Steps in Hardy Cross Method

1) Assume reasonable rates of flow in each pipe such that the inflow equals outflow in each junction
2) In each loop, determine the head loss, H and H/Q for all pipes
3) Compute the total head loss around each circuit with giving due consideration to sign
4) Compute $\sum H/Q$ for the same circuit without giving any consideration to sign
5) Calculate the correction, Δ for each loop and apply to each loop. When the sign of Δ is negative, decrease the clockwise flow, increase the counterclockwise flow and vice versa
6) With adjusted flows, repeat the procedure until desired accuracy is obtained

Example Problem

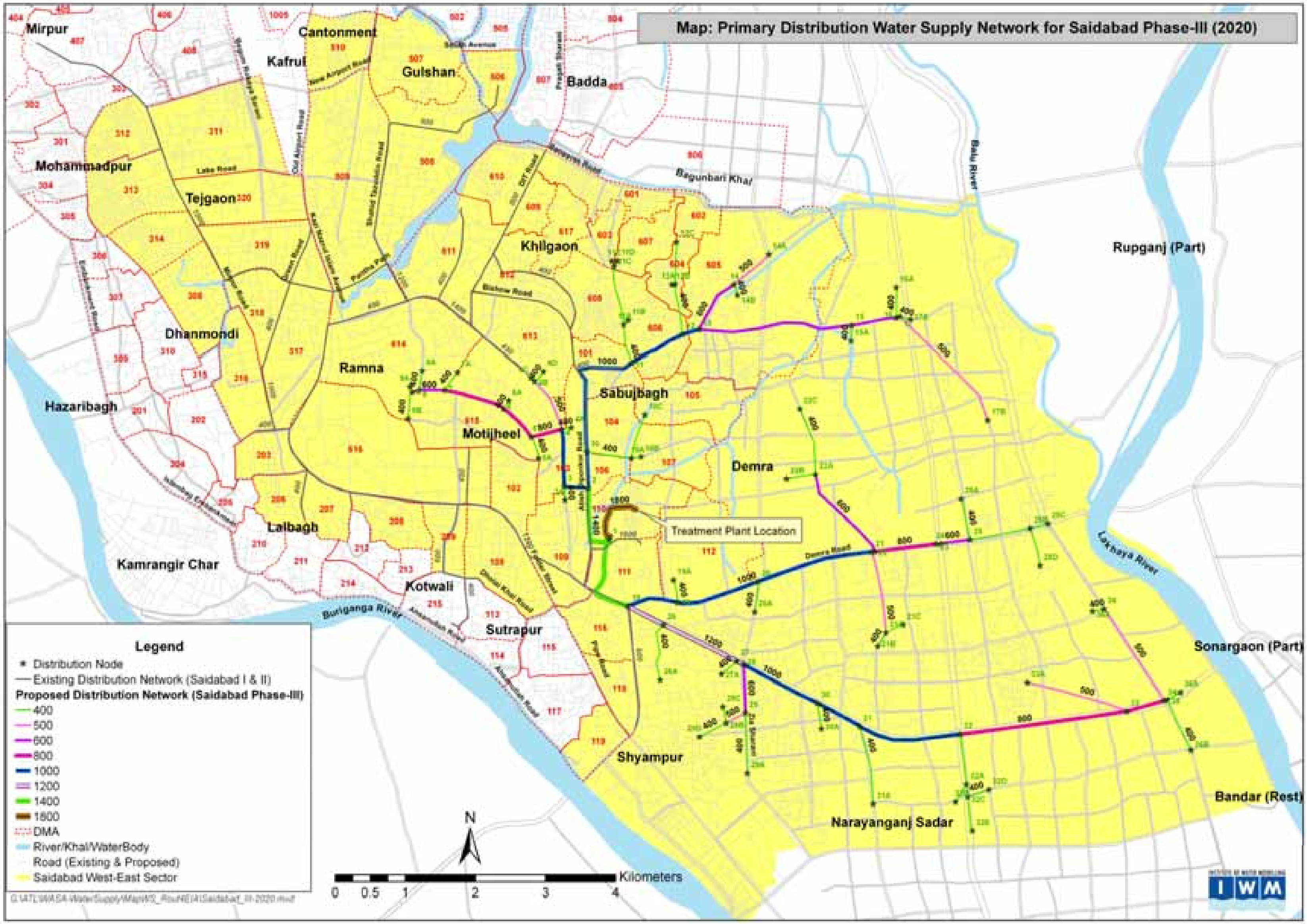
Calculate the flow in each of the pipes in the following looped pipe network



Week-(07)

MD Ehasan Kabir

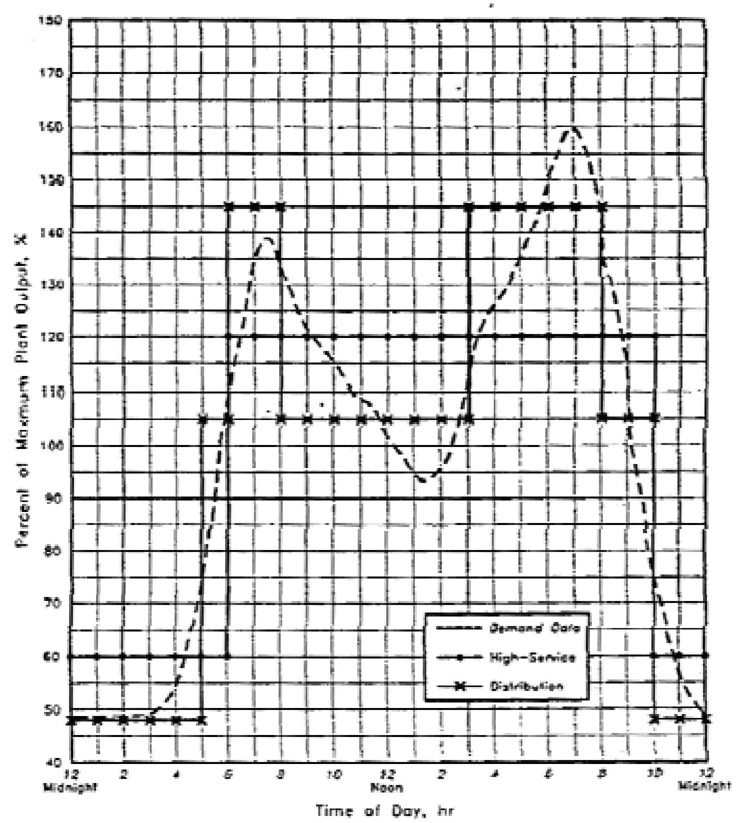
Water Distribution Network: Saidabad ph-III



Storage Reservoir

Constructed in the distribution system to provide storage to meet the fluctuation of water demand, stabilize pressure and provide storage for emergency requirements

In the absence of storage reservoir
-Pumping has to continue for all hours of supply
-Pumping has to be regulated to meet the fluctuation of demand



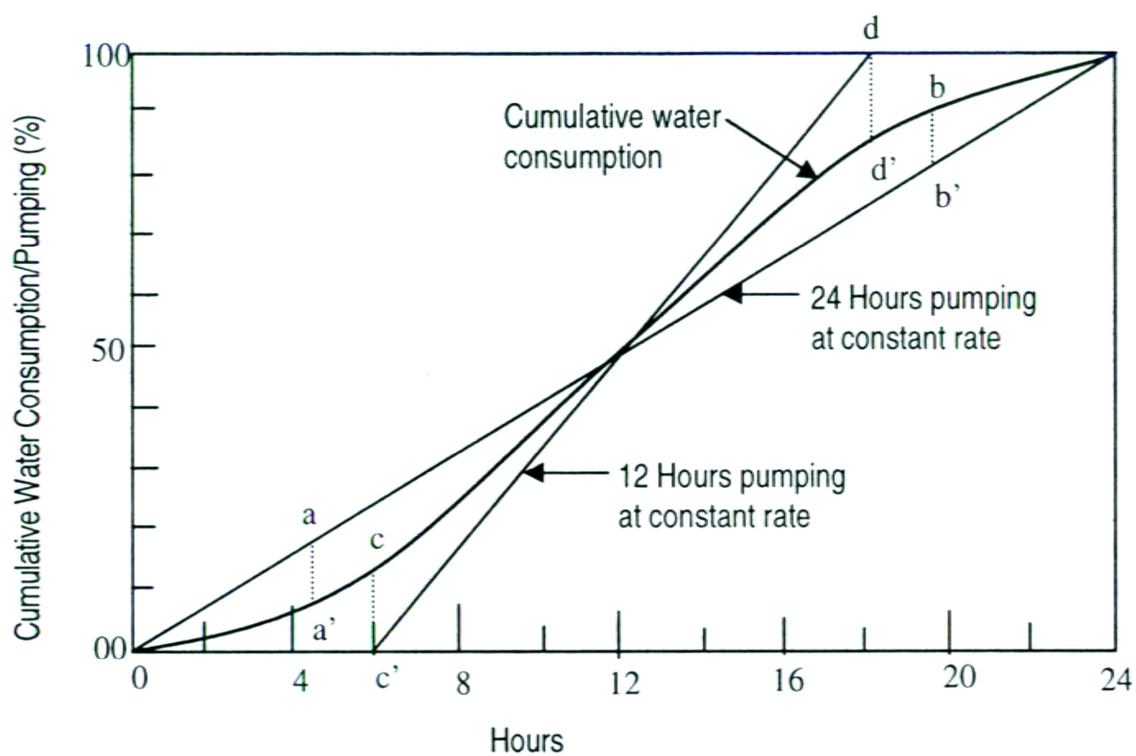
This is not technically and economically feasible

How to Design a Storage Reservoir

Steps:

-Cumulative water demand and supply at different hours of a peak day are plotted

-The algebraic sum of the highest differences in demand and supply is the capacity of the storage reservoir

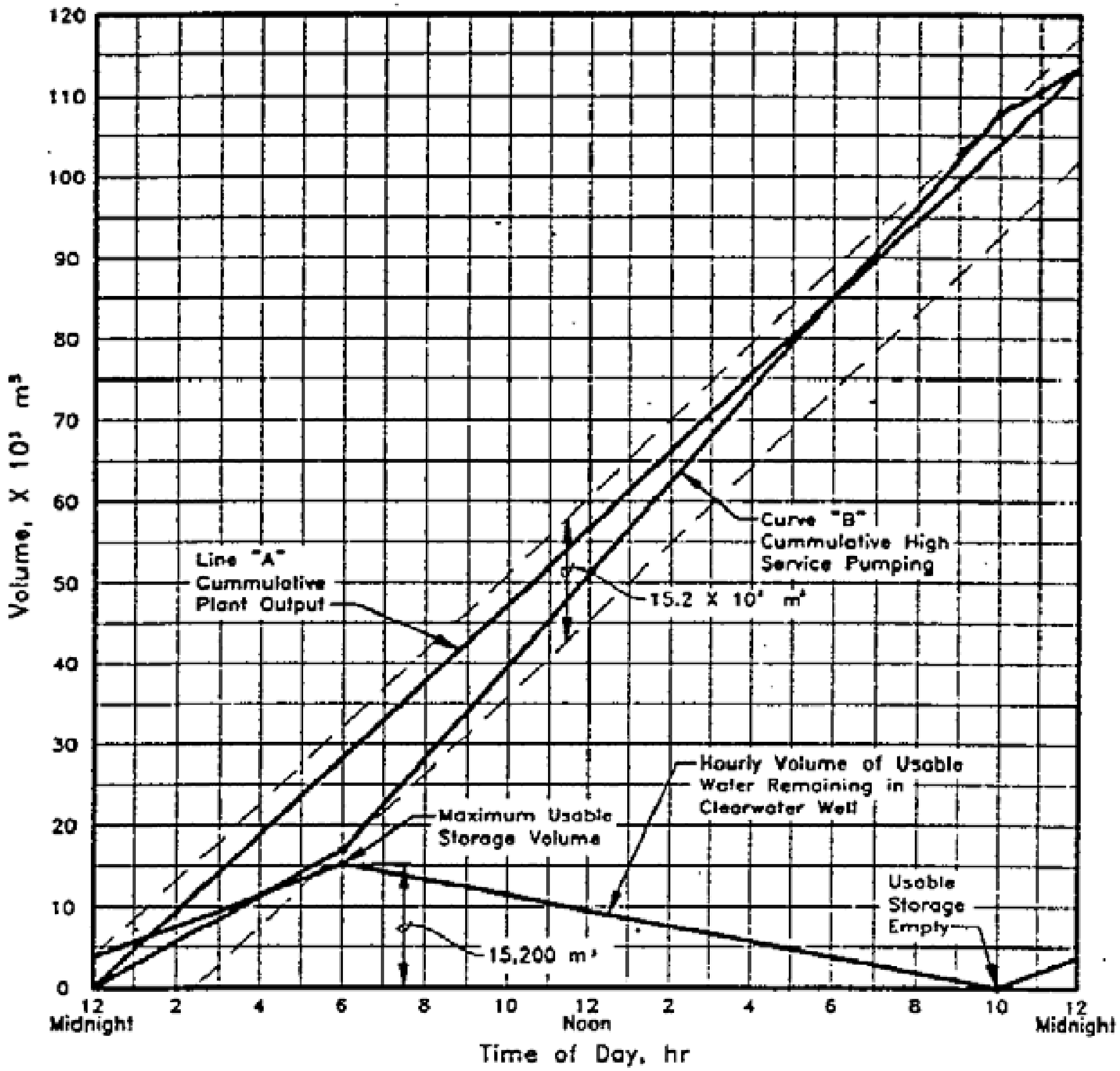


Example Problem

Determine the storage volume of an overhead tank to balance the treatment plant output of 113500 m^3/day with the high service pumping with the following schedule:

12 Midnight – 6A.M. = 2.83 m^3/hr
6 A.M. – 10 P.M. = 5.68 m^3/hr
10 P.M. – 12 Midnight = m^3/hr

Example Problem



Storage Reservoirs in Dhaka City

Overhead Tanks at Mohakhali DOHS and Gulshan-I

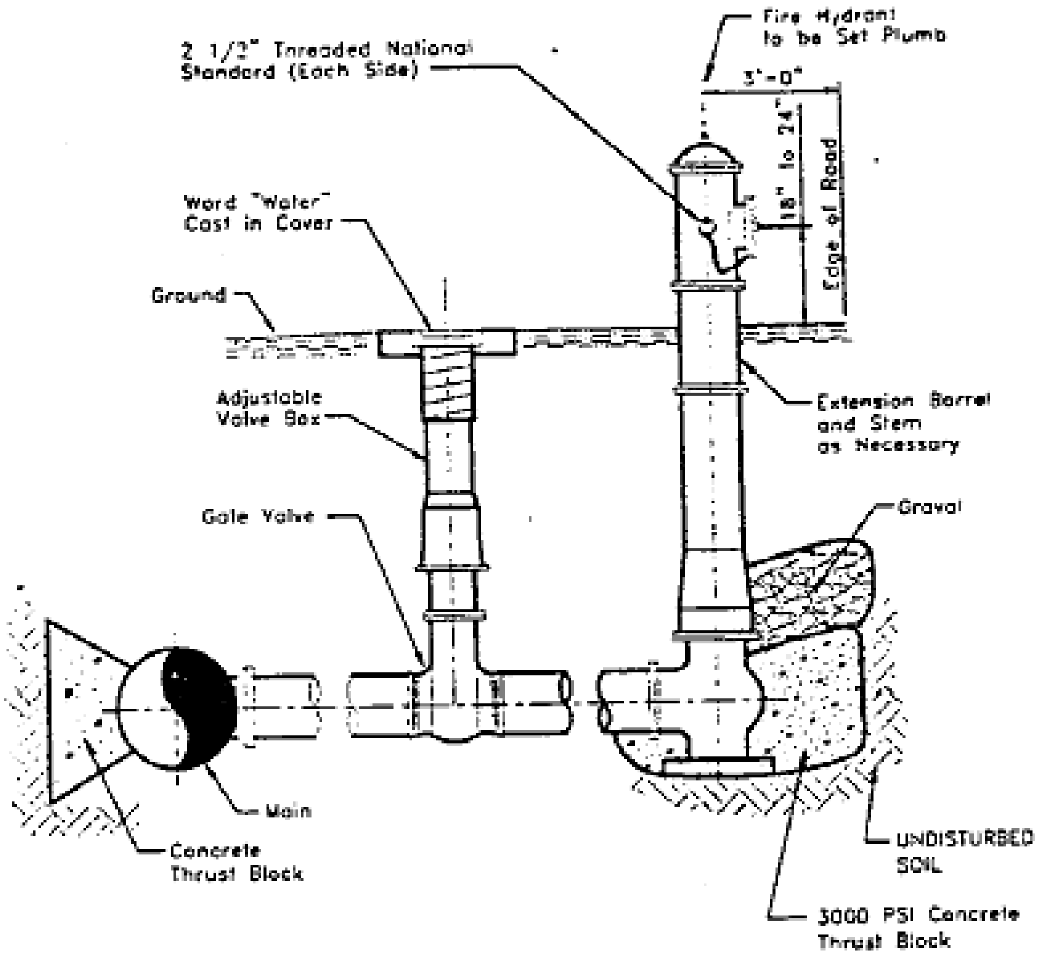
DWASA has 43 Overhead tanks, 17 of which are currently operational

Fire Hydrant

An outlet from a water main provided chiefly for the purpose of forming a connection with a fire hose

Usually made of cast iron with bronze surfaces

A gate valve is desirable in addition to the main valve



Fire Hydrant

Placement: footpath or street corner near the curb (street intersections as well as intermediate points). According to the National Board of Fire Underwriters, a spacing of 200 ft is required for a community of 25000 to 30000 population requiring a fire flow of 5000 gpm. For small communities requiring only 1000 gpm of fire flow, the requirement is 300 ft.

Other requirements:

- Should be able to deliver 600 gpm with a loss of not more than 2.5 psi in the hydrant and a total loss of not more than 5 psi between the street main and the outlet.
- Not less than 2.5 inch outlets
- Large suction connection where engine service is necessary
- Hydrant should remain closed when barrel is broken off
- Street connections not less than 6 inch diameter and shall be gated
- Size: at least 4" for two 2.5" nozzles, at least 5" for three 2.5" nozzles, at least 6" for four 2.5" nozzles

Non-Revenue Water (NRW)

Non revenue water (NRW) is water that has been produced and is "lost" before it reaches the customer.

NRW has the following components:

- Unbilled authorized consumption (firefighting, public area landscaping etc.)
- Apparent losses (water theft and metering inaccuracies)
- Real losses (from transmission mains, storage facilities, distribution mains or service connections)

⇓

Unaccounted for Water

NRW Indicators

%NRW as a share of water produced:
-Most common and easy to understand
-not an appropriate indicator to benchmark NRW levels between utilities or even to monitor changes over time

Losses per connection per day: - recommended by IWA

Percentage, losses per connection or losses per km of network together:
-Recommended by The International Benchmarking Network for Water and Sanitation
- Losses per kilometer of network are more appropriate to benchmark real losses, while losses per connection are more appropriate to benchmark apparent losses.

Benefits of NRW Reduction

- financial gains from increased water sales or reduced water production, including possibly the delay of costly capacity expansion;
- increased knowledge about the distribution system;
- increased firefighting capability due to increased pressure;
- reduced property damage;
- reduced risk of contamination
- More stabilized water pressure throughout the system

Reading Materials for this Lecture

Chapter 20: Water Supply and Sanitation (by F. Ahmed and M. Rahman)

http://en.wikipedia.org/wiki/Non-revenue_water

Week-(08)

MD Ehasan Kabir

Flow Through Conduits

Two classes of flow in water supply systems

Open channel flow

Top surface under atmospheric pressure, flow occurs due to gravity over a sloping conduit bottom

- **Canals**
- **Flumes and aqueducts**
- **Gravity conduits**
- **Grade tunnels**

Pressure flow

Water in pipe under > atmospheric pressure, flow occurs due to a head difference

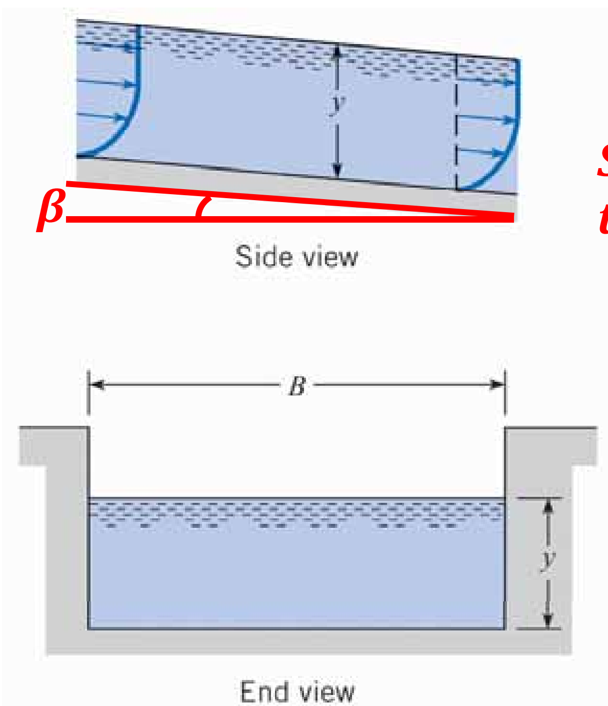
- **Pressure conduits**

Open Channel Flow

Two traditional formula have been used to estimate the velocity, *V*

Chezy's equation

$$V = C\sqrt{RS}$$



S ≈ tanβ

R = By/(2y+B)

Manning's equation

$$V = \frac{1}{n} R^{2/3} S^{1/2} \quad \text{(SI)}$$

$$V = \frac{1.49}{n} R^{2/3} S^{1/2} \quad \text{(British)}$$

C, n = coefficients which depend on the roughness of the surface

S = slope of the channel

R = hydraulic radius

= wetted area/wetted perimeter

Open Channel Flow

Table 15.1 TYPICAL VALUES OF ROUGHNESS COEFFICIENT, MANNING'S *n*

Lined Canals	*n*
Cement plaster	0.011
Untreated gunite	0.016
Wood, planed	0.012
Wood, unplaned	0.013
Concrete, troweled	0.012
Concrete, wood forms, unfinished	0.015
Rubble in cement	0.020
Asphalt, smooth	0.013
Asphalt, rough	0.016
Corrugated metal	0.024
Unlined Canals	
Earth, straight and uniform	0.023
Earth, winding and weedy banks	0.035
Cut in rock, straight and uniform	0.030
Cut in rock, jagged and irregular	0.045
Natural Channels	
Gravel beds, straight	0.025
Gravel beds plus large boulders	0.040
Earth, straight, with some grass	0.026
Earth, winding, no vegetation	0.030
Earth, winding, weedy banks	0.050
Earth, very weedy and overgrown	0.080

Reference: Crowe et al "Engineering Fluid Mechanics" (Ninth Edition)

Flow in Pressure Pipes

Hazen Williams formula to estimate velocity in pipes

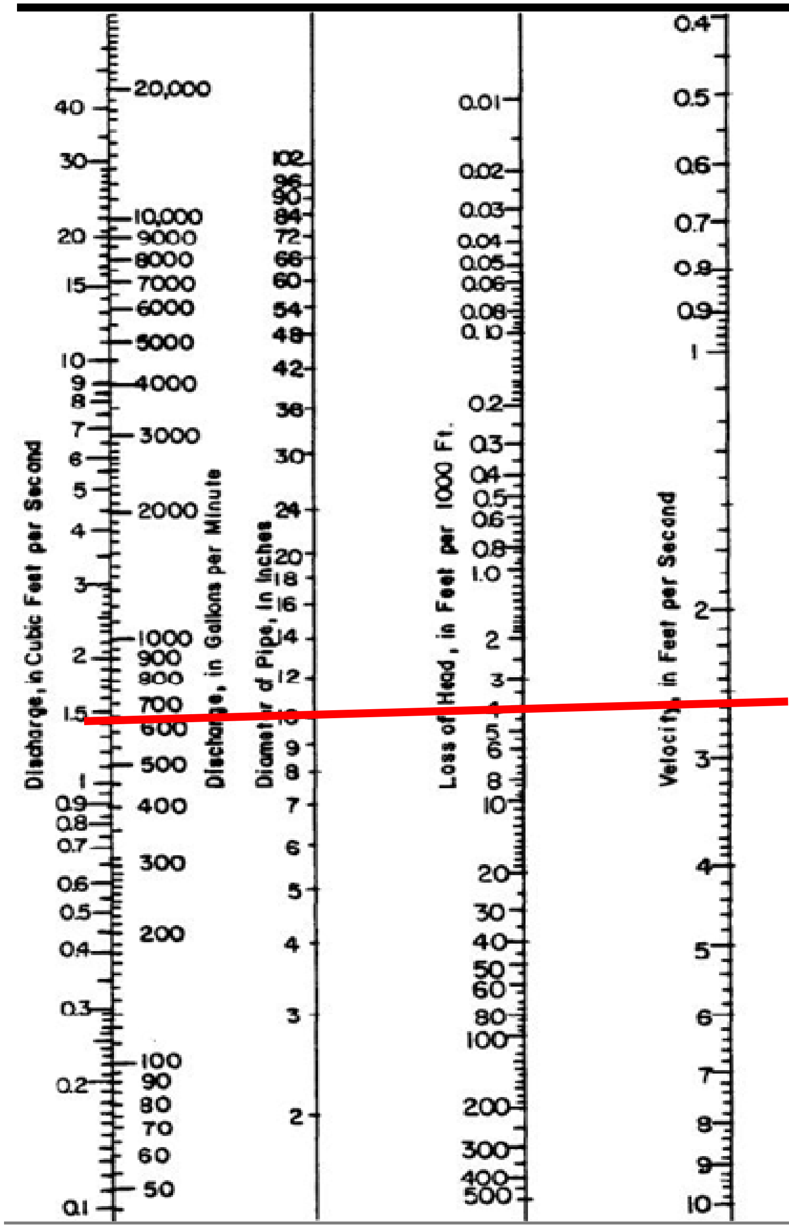
$$V = 1.318\,CR^{0.63} h_L^{0.54}$$

$$V = 0.55 CD^{0.63} h_L^{0.54}$$

C = A coefficient which depends on the type and condition of the conduit
h_L = loss of head in feet per foot length
R = hydraulic radius in feet
D = diameter = 4R

C value	Type of conduit
140	Smooth lined steel pipe, very smooth concrete and for smooth new cast iron pipe
130	Ordinary cast iron pipe in good condition
120	Cast iron pipe (5 years old), welded steel pipe
110	Cast iron pipe (10 years), new unlined riveted steel pipe
100	Cast iron pipe (15 to 20 years)
95	Unlined riveted steel pipe in service

Hazen William's Nomograph for C=100



$$V = 0.55CD^{0.63}h_L^{0.54}$$

Applicability of this chart:

- Circular pipes flowing full under pressure
- The only cause of loss is friction in pipes
- *C* = 100 (a correction is required if it is to be used for other *C* values)

$$V, Q \propto C$$

Problem: A 10 inch pipe for which C = 130 is discharging 825 gpm. What is the loss of head per 1000 ft?

[corrected Q for C =100 is: 825×(100/130) = 635 gpm.
A straightedge through diameter 10 inch and discharge 635 gpm gives hL = 4.2 ft per 1000 ft]

Design considerations

Hydraulic Transitions: Different flow regimes (Supercritical/subcritical) depending on relative velocity and amount of turbulence

Water Quality: natural or anthropogenic pollution in open channel flow

Erosion Control: A maximum permissible velocity is usually set to prevent erosion

Seepage and Evaporation loss: in arid regions or area with high soil permeability

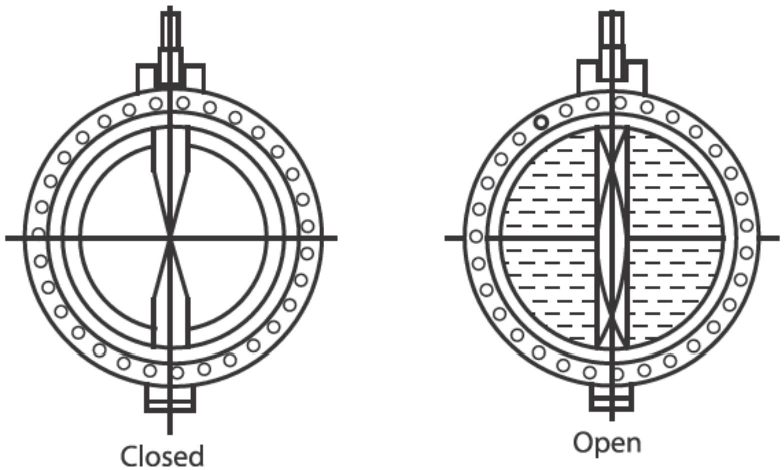
Air Control: In pressure pipes, air trapped gets accumulated at the high points and cause friction loss (air release valves used)

Transiet Pressure Wave: Due to abrupt change in velocity or direction of flow of water (surge towers, surge control valves used)

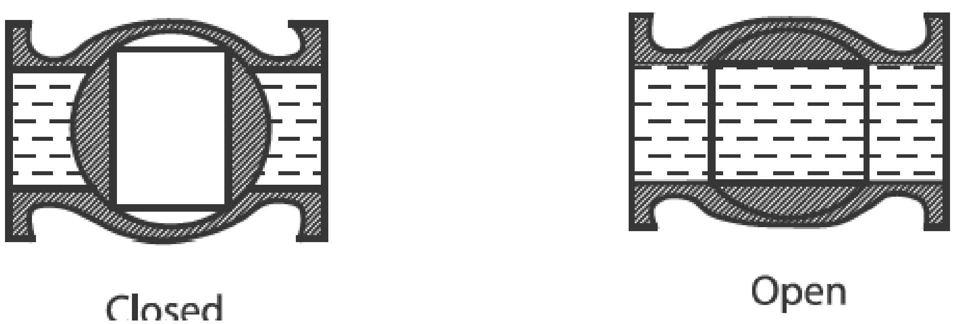
Valves in Conveyance System

Isolation Valves:

- purpose is to isolate segments of pipeline
- Should provide a tight seal and have low head loss when fully open
- Gate valves, butterfly valves, ball and globe valves



Butterfly valve



Ball valve

Valves in Conveyance System

Valves for regulating flow:
- Used to regulate or throttle the rate of flow
- Must have a tight seal when closed, low cavitation potential and a near-linear relationship between headloss and percent opening

Air-Relief valves:
- purpose is to release the air accumulated at high points in pipelines

Surge control valves
- To prevent the propagation of transient pressure waves due to change in pumping rate or closure of a valve on a pressure pipeline
- Typically globe valves or special plug valves with elaborate controls to ensure rapid opening and slow closing

Desirable Qualities of Pressure Pipes

- Durability of pipe material
- Strength and thickness (resist stress)
- Smooth inner surface (avoid friction loss)
- No effect on water
- light weight (ease of transportation, handling and laying)
- low initial cost with a maximum service period
- low maintenance cost, joints can be made easily, good against a corrosive environment
- good hydraulic properties

Types of Pressure Pipes

Steel pipe

- Riveting or welding large steel plates.
- Can be made thin because the material has good flexural strength
- Coating by painting (external and internal)

Cast-iron pipe

- widely used for city water supplies
- Durable, ease of laying, joining and resistant to corrosion
- cement-mortar lining for good hydraulic properties

Types of Pressure Pipes

Concrete pipe

- Good hydraulic properties, leakage is small if properly laid, alkaline water may cause deterioration
- Can be precast or cast *in situ*
- Prestressed pipes requires less steel and weighs less, but costlier

Asbestos-cement pipe

- light weight, can be easily assembled
- High hydraulic efficiency, resistant against corrosion, tuberculation and incrustation
- does not have high strength in bending

Types of Pressure Pipes

<u>Vitrified clay pipe</u>

- free from corrosion, smooth surface (good hydraulic properties)
- Cannot withstand high pressure, so mostly used as gravity pipes.

<u>PVC pipe</u>

- lightweight, easy to handle, resistant to tuberculation, incrustation
- Cannot withstand high temperatures

Types of Pressure Pipes

GI pipe

- great serviceability
- for acidic water, there may be lead poisoning

Copper pipe

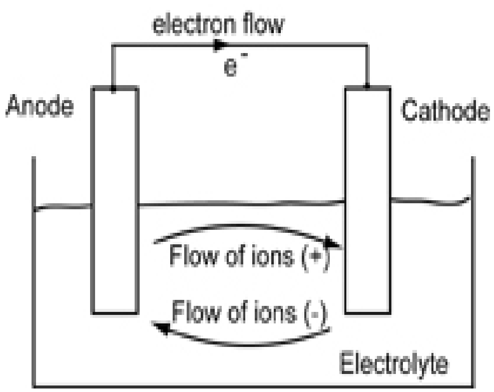
Expensive but may be useful where corrosion is likely to occur

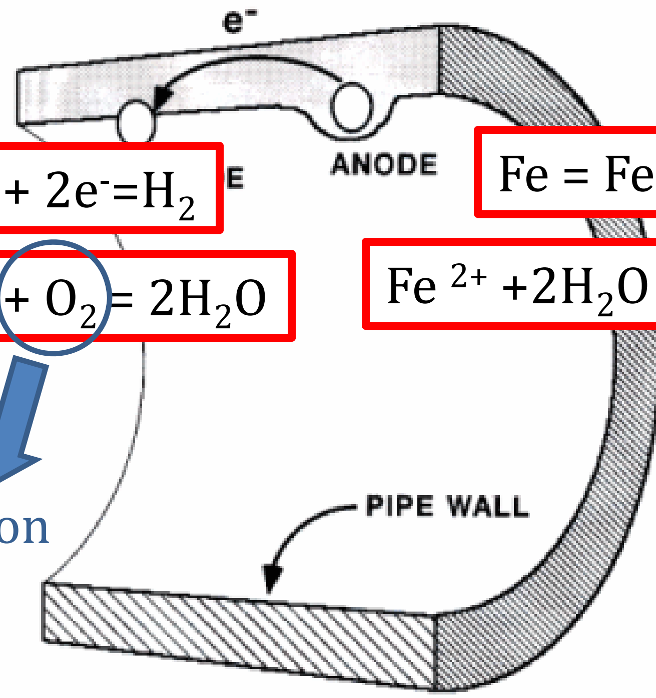
Plastic pipe

Corrosion free, lightweight but not very strong. Cannot be used in large sizes.

Corrosion in Metal Pipes

A process by which metals and their alloys are destroyed by chemical, electro-chemical means or by the action of physical forces.





$2H^+ + 2e^- = H_2$

$2H_2 + O_2 = 2H_2O$

Promotes corrosion

$Fe = Fe^{2+} + 2e^-$

$Fe^{2+} + 2H_2O = Fe(OH)_2 + 2H^+$

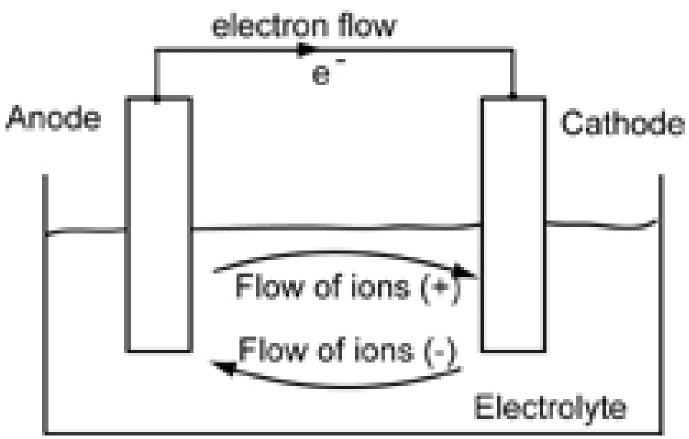
Rust

Tuberculation

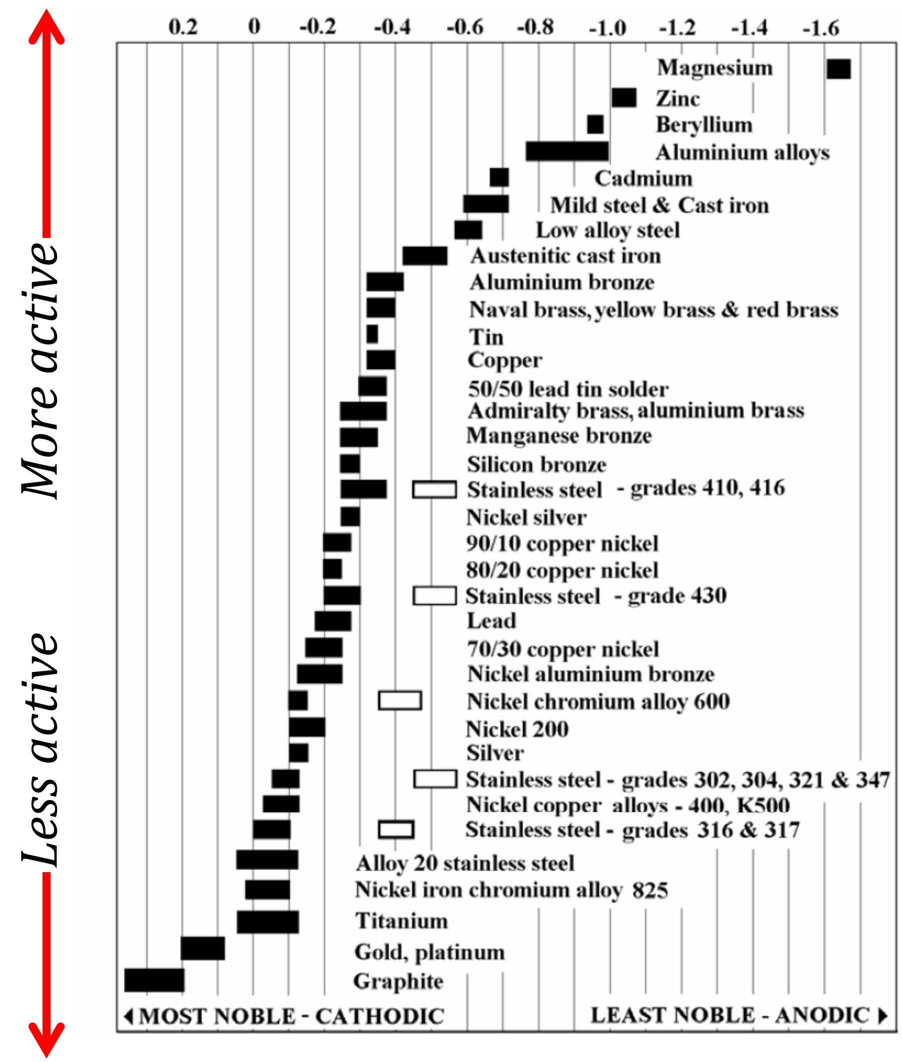
Formation of granular insoluble $Fe(OH)_3$ granular deposits inside the pipe.

Galvanic Corrosion

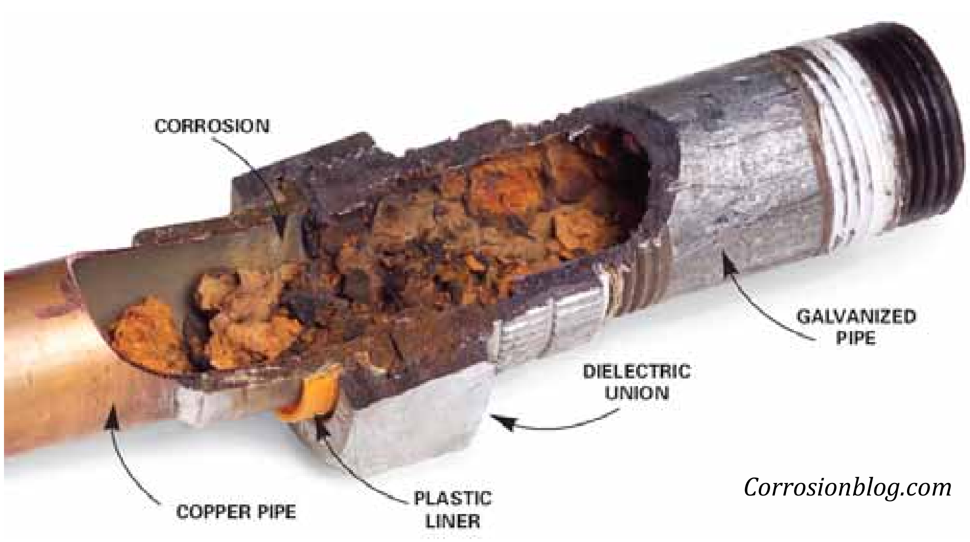
When two metals are immersed in an electrolyte, the comparatively more active metal becomes the anode and corrodes.

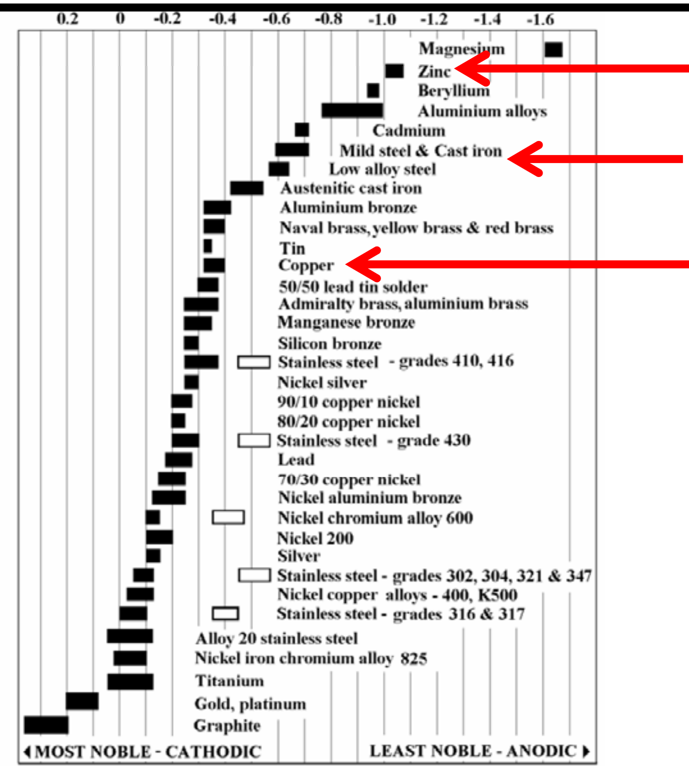


Rate of electrolysis depends on:
(1) the relative position of the metals in the galvanic series
(2) relative surface area of the anodes and cathodes



Galvanic Corrosion





May occur in

(1) pipes and fittings of different type of metals

(2) between the pipe metal and the impurities in the pipe metal

<u>Prevention:</u>

(1) Using insulators

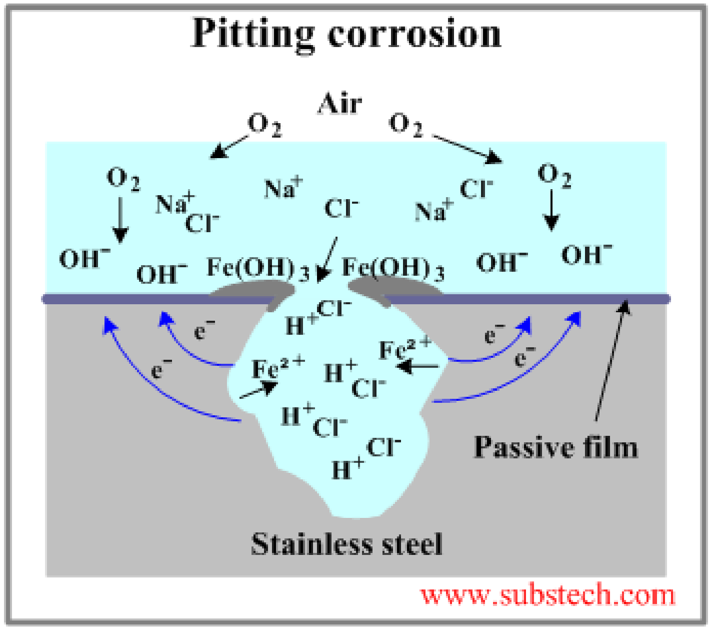
(2) Use protective materials (e.g. paint, bituminous compounds)

(3) Using materials with similar electric poetentials

(4) Using metallic coatings (e.g. Zinc, tin, Nickel, Chromium)

Pitting Corrosion

An electrochemical redox process occuring within localized holes on the surface of the metal. This is worse than uniform corrosion.



Octane.nmt.edu

Starts from a mechanical damage on the protective surface.

Reactions: $Fe = Fe^{2+} + 2e^-$

$\frac{1}{2} O_2 + 2e^- + H_2O = 2(OH)^-$

$FeCl_2 + 2H_2O = Fe(OH)_2 + 2HCl$

Presence of Chloride ion and dissolved oxygen accelerates pitting

More info: http://www.substech.com/dokuwiki/doku.php?id=pitting_corrosion

Microbial Action (External Corrosion)

Sulphates in the environment

Anaerobic environment
Nutrients

Vibrio desulphuricans

Hydrogen Sulphide

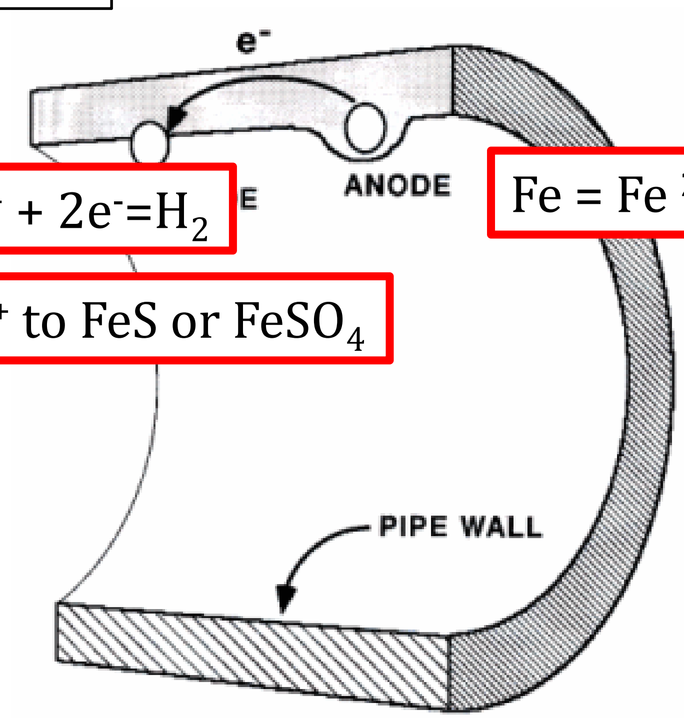
Water

Sulphuric Acid

$2H^{+} + 2e^{-} = H_2$

$Fe = Fe^{2+} + 2e^{-}$

Fe^{2+} to FeS or $FeSO_4$



Acidic (low pH) and low alkaline environment helps corrosion.

Other Factors Affecting Corrosion

TDS and temperature

TDS influences the electrical conductivity. Temperature affects reaction rates.

Velocity of water

Shear exerted by high velocity water can remove tubercules, expose new pipe materials and promote corrosion. Also turbulent flow has an abrasive effect.

Cavitation

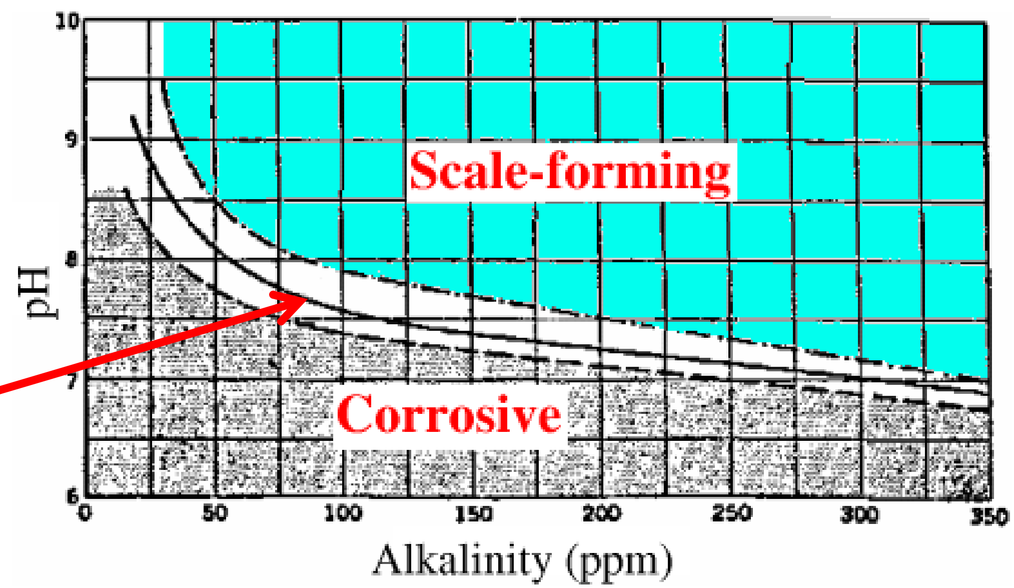
Bombardment of surroundings with particles of water and water vapour accelerate corrosion.

Water Stability

The tendency of corrosive water to dissolve minerals can be detrimental to water quality (lead and copper pollution)

Some scale formation is useful in preventing corrosion. But excessive scaling will render the pipe network unusable (damage appliances, increase pipe friction, clogging)

Bayliss curve

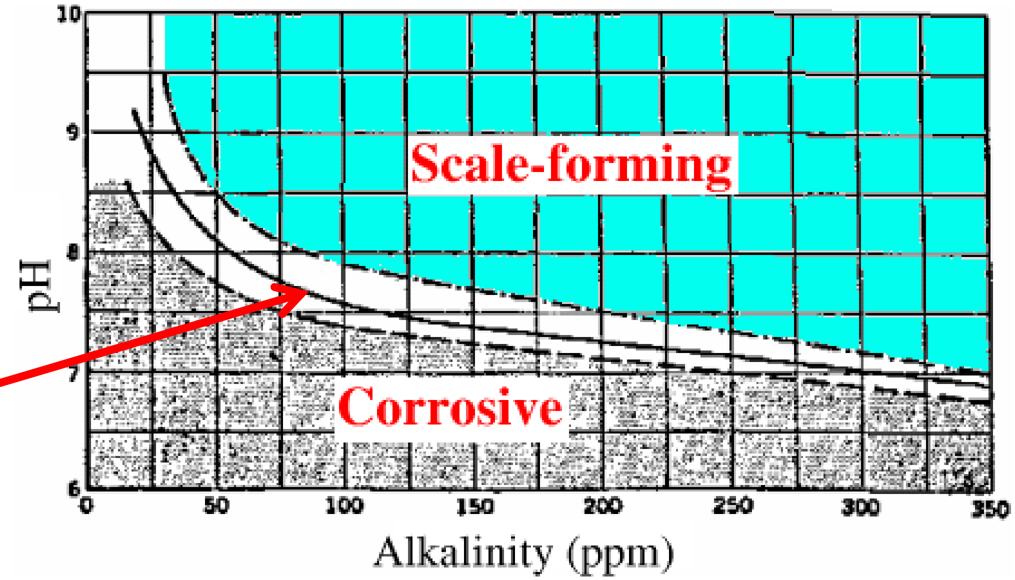


Objective of water treatment is to obtain stable water

Corrosive and Scale-forming Water

Corrosive Water	Scale forming water
•Low pH •Low Alkalinity •Soft or with primarily noncarbonate hardness	•High pH •High Alkalinity •Hard or with primarily carbonate hardness

Bayliss curve



Objective of water treatment is to obtain stable water

Week-(09)

MD Ehasan Kabir

Methods to Measure Water Stability

Langelier Saturation Index (LI)**:** compares the pH of the water to the pH of water if it were saturated with Calcium Carbonate

$$LI = pH - pH_S$$

$$pH_S = (pK_2 - pK_S) + pCa^{2+} + pAlk$$

$pK_2 - pK_S$ = constants based on the ionic strength and TDS of water
pCa^{2+} = negative logarithm of Calcium ion in moles/liter
$pAlk$ = negative logarithm of total alkalinity in equivalents/liter

$LI < 0$ water is corrosive
$LI > 0$ water is scale-forming

Value of pK_2 - pK_S

TDS, mg/L	$pK_2 - pK_s$ 0°C	10°C	20°C	30°C	40°C	50°C	80°C
	2.45	2.23	2.02	1.86	1.68	1.52	1.08
40	2.58	2.36	2.15	1.99	1.81	1.65	1.21
80	2.62	2.40	2.19	2.03	1.85	1.69	1.25
120	2.66	2.44	2.23	2.07	1.89	1.73	1.29
160	2.68	2.46	2.25	2.09	1.91	1.75	1.31
200	2.71	2.49	2.28	2.12	1.94	1.78	1.34
240	2.74	2.52	2.31	2.15	1.97	1.81	1.37
280	2.76	2.54	2.33	2.17	1.99	1.83	1.39
320	2.78	2.56	2.35	2.19	2.01	1.85	1.41
360	2.79	2.57	2.36	2.20	2.02	1.86	1.42
400	2.81	2.59	2.38	2.22	2.04	1.88	1.44
440	2.83	2.61	2.40	2.24	2.06	1.90	1.46
480	2.84	2.62	2.41	2.25	2.07	1.91	1.47
520	2.86	2.64	2.43	2.27	2.09	1.93	1.49
560	2.87	2.65	2.44	2.28	2.10	1.94	1.50
600	2.88	2.66	2.45	2.29	2.11	1.95	1.51
640	2.90	2.68	2.47	2.31	2.13	1.97	1.53
680	2.91	2.69	2.48	2.32	2.14	1.98	1.54
720	2.92	2.70	2.49	2.33	2.15	1.99	1.55
760	2.92	2.70	2.49	2.33	2.15	1.99	1.55
800	2.93	2.71	2.50	2.34	2.16	2.00	1.56

Methods to Measure Water Stability

Ryznar Index (LI)**:** indicates the severity of corrosivity or scaling tendency

$$RI = 2\,pH_S - pH$$

RI Range	Indication
Less than 5.5	Heavy scale formation
5.5 to 6.2	Some scale will form
6.2 to 6.8	Non-scaling or non-corrosive
6.8 to 8.5	Corrosive water
More than 8.5	Very corrosive water

Example Problem

Raw water quality data:

a. Total alkalinity : 80 – 110 mg/L as $CaCO_3$

bicarbonate alkalinity: 80 – 110 mg/L as $CaCO_3$

b. Hardness: 100 – 120 mg/L as C aCO_3

i. Calcium = 38 – 46 mg/L as Ca^{2+}

ii. Magnesium = 1.2 mg/L as Mg^{2+}

c. TDS = 200 – 250 mg/L

d. pH = 7.5 to 8.2

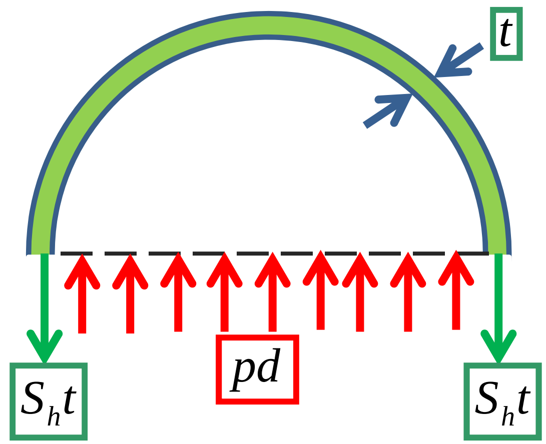
e. Temperature = 5 – 30 deg. C

Comment on the stability of water.

Forces Acting on Pipes

Internal Forces due to Static Head

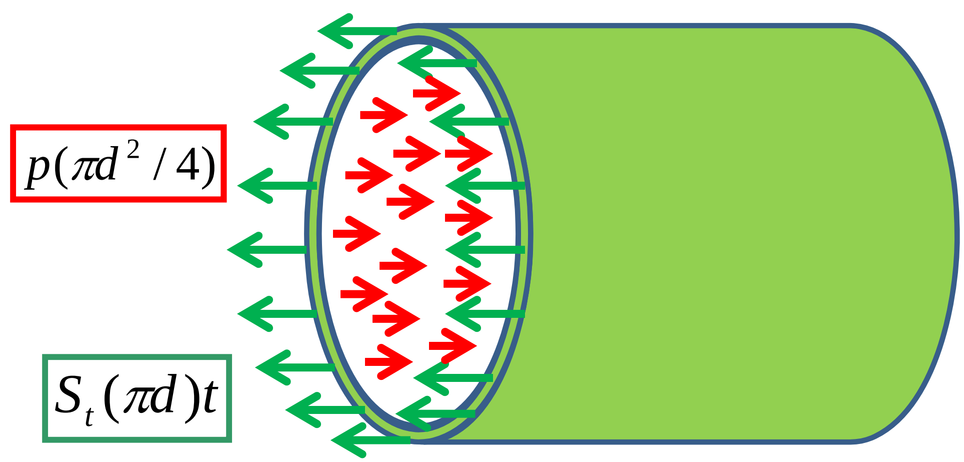
Hoop stress, $S_h = \dfrac{pd}{2t}$



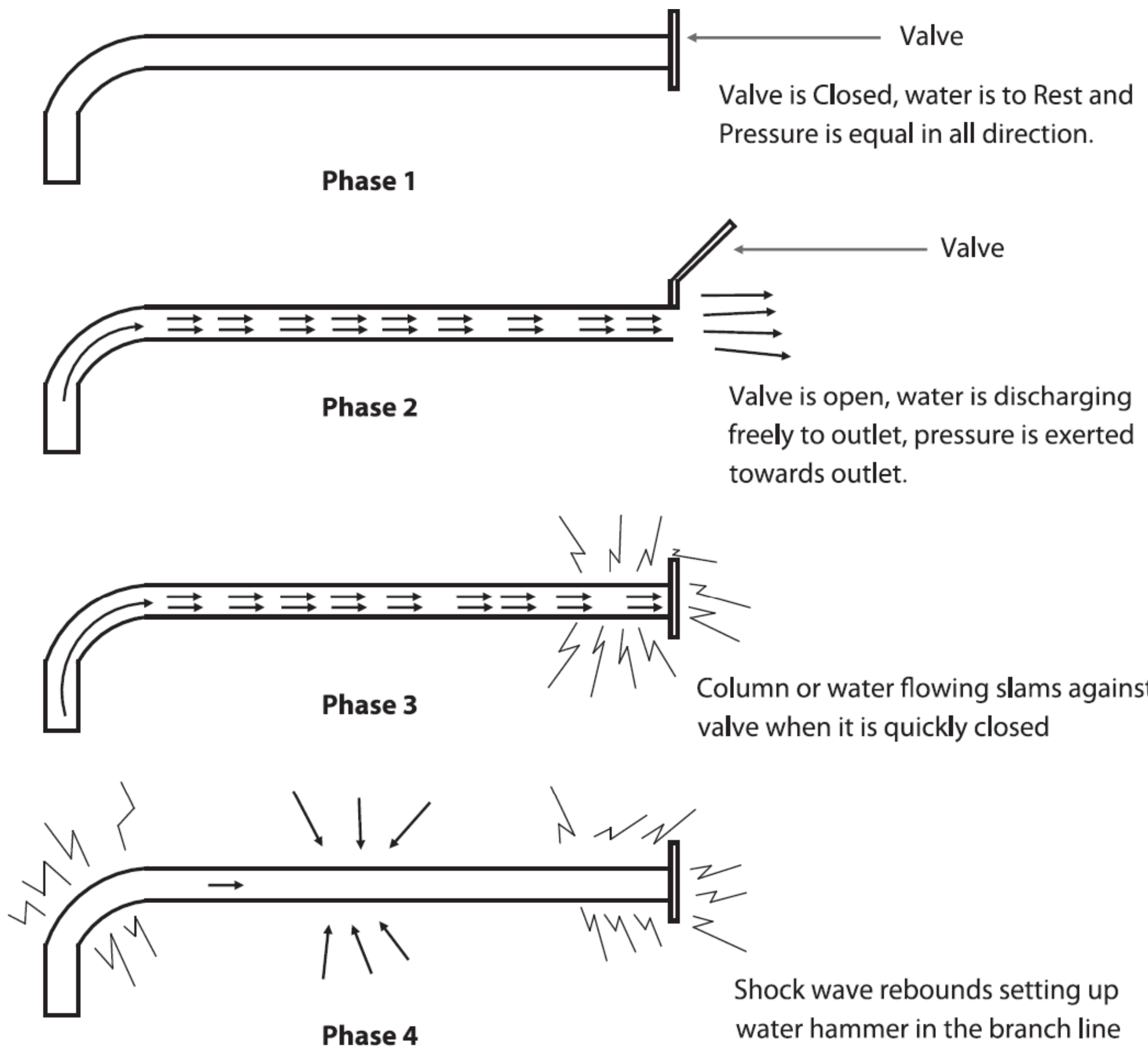
d = diameter of pipe
p = water pressure

Longitudinal (tensile) stress

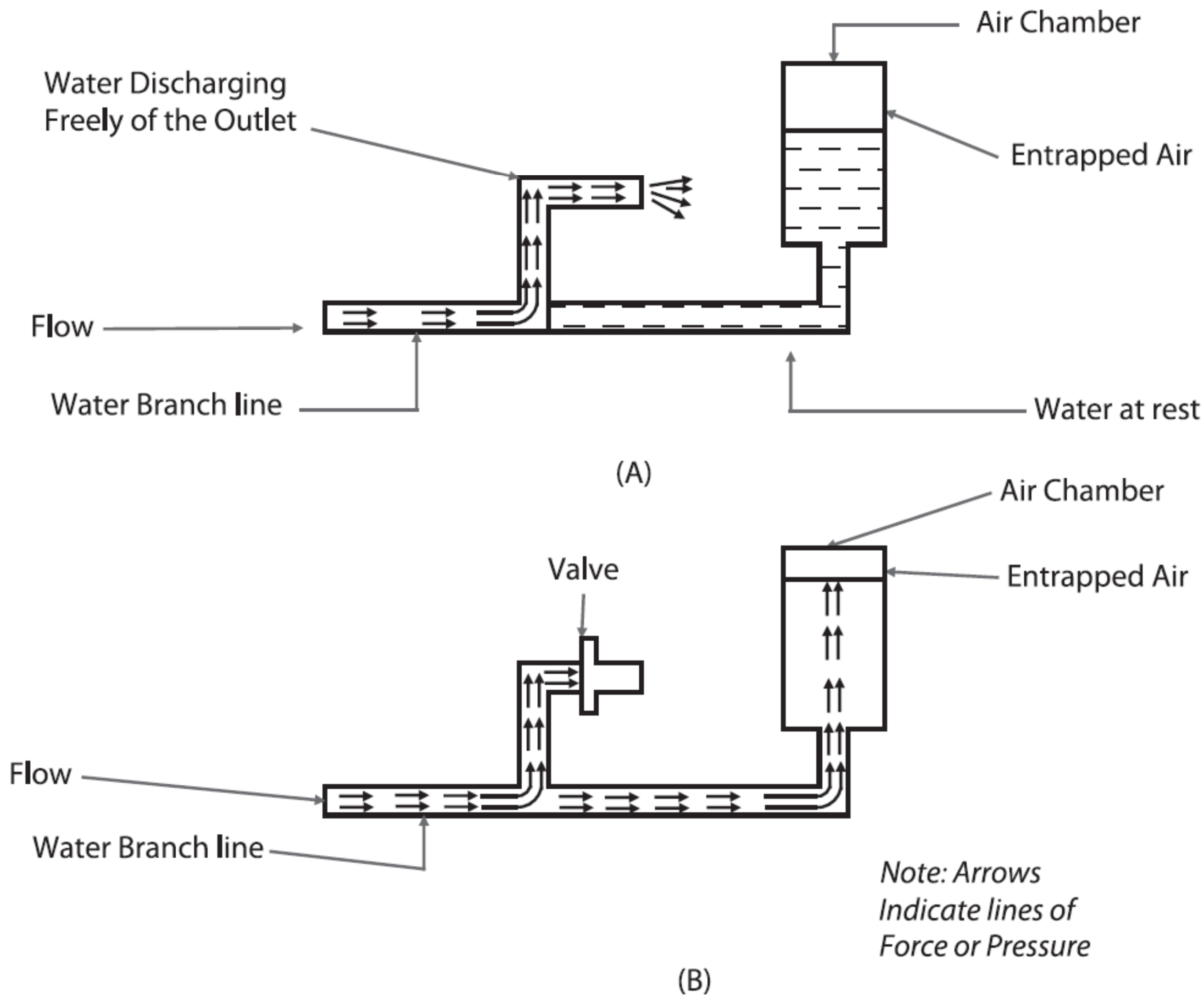
$$S_t = \frac{pd}{4t}$$



Forces Acting on Pipes: Water Hammer



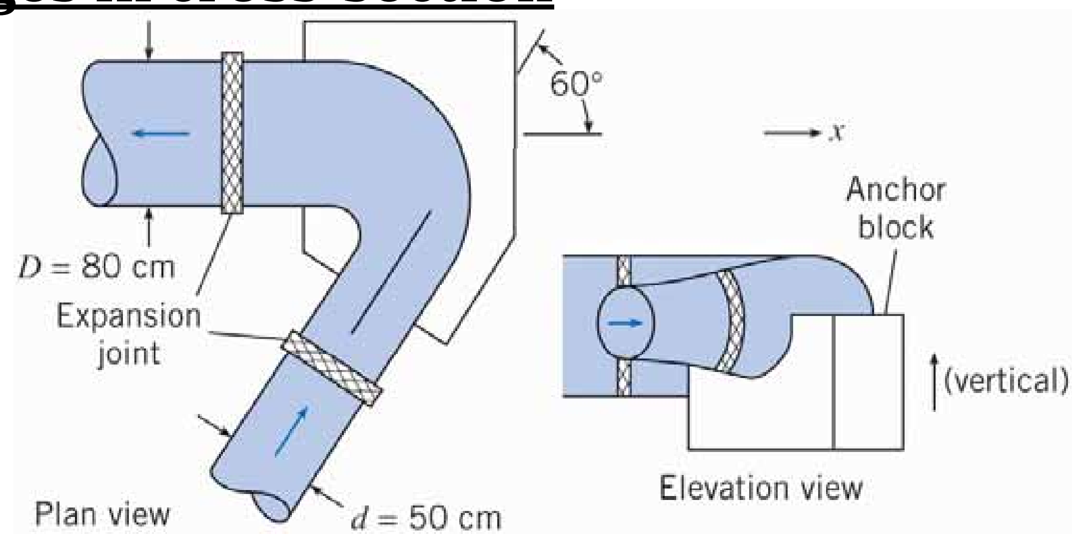
Preventing Water Hammer



Forces Acting on Pipes

Forces at bends and changes in cross-section

Can be calculated using conservation of momentum in conjuction with Bernoulli's equation (Ref: WRE 201)



Forces due to temperature changes

Longitudinal stress, $\sigma = E \alpha \Delta T$

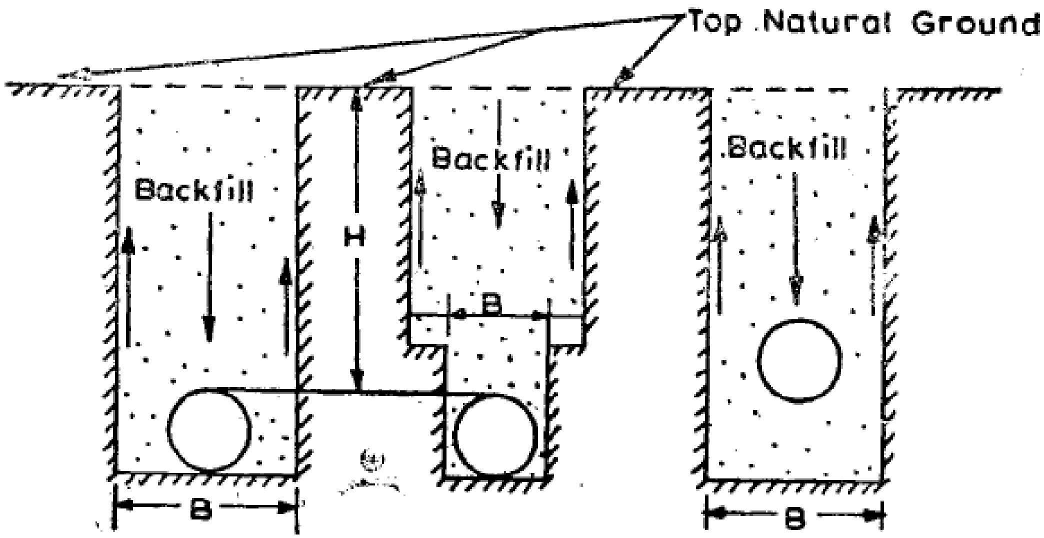
Modulus of Elasticity (E) — Coefficient of thermal expansion (α)

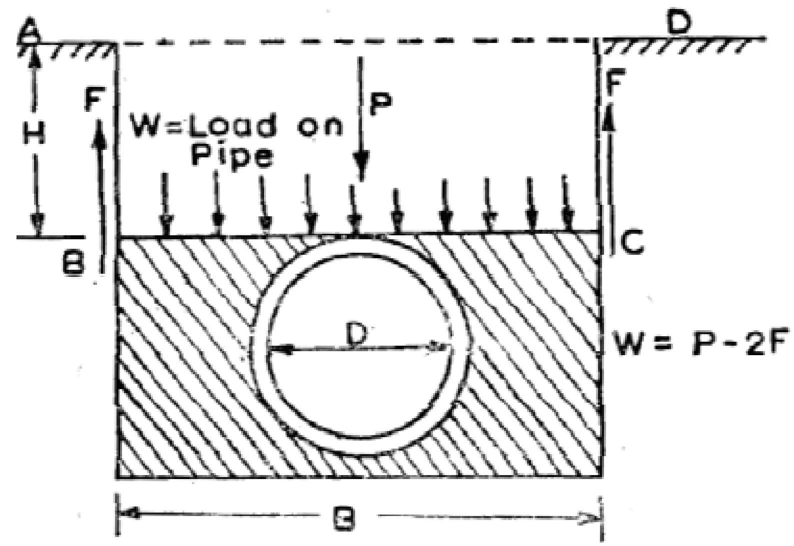
Expansion joints provided to reduce temperature stress

Forces Acting on Pipes

External forces due to backfill

Force on a horizontal plane above the pipe due to backfill
=Weight of the backfill – shear force between the fill material and trench





Force depends on:
(1) rigidity of the pipe (2) type of fill material (3) character of bedding

Forces Acting on Pipes

Rigid pipe: $w = c\gamma B^2$

Flexible pipe: $w = c\gamma BD$

w = load (pounds per foot)
γ = specific weight (pound per cu.ft)
c = load calculation coefficient

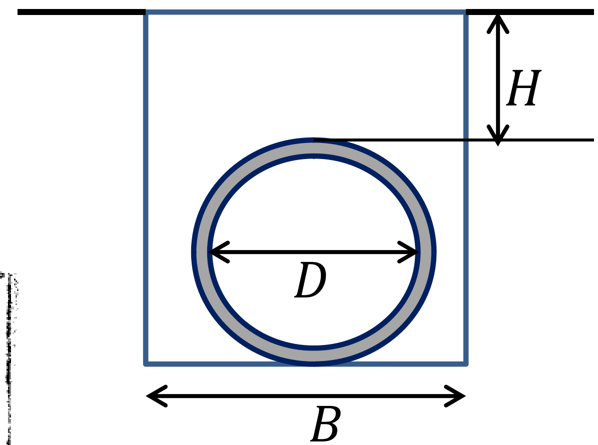
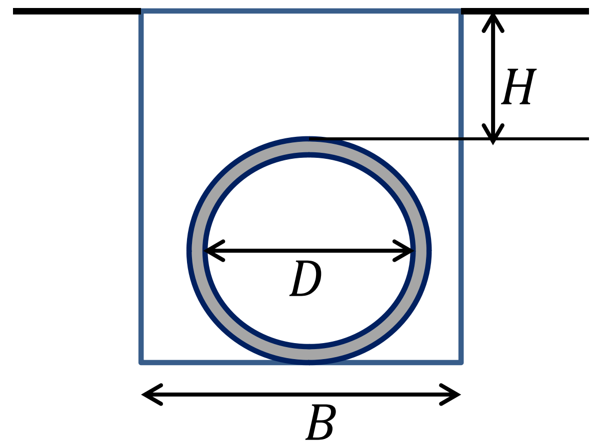


Table 4.1 Values of the coefficient c for Eqs. 4.8 and 4 9.

Fill Material	Sand and gravel	Saturated top soil	Clay	Saturated Clay
Specific weight lb/cu ft.	100	100	120	130
Cover depth / Trench width = H/B	Values of c			
1.0	0.84	0.86	0.88	0.90
2.0	1.45	1.50	1.55	1.62
3.0	1.90	2.00	2.10	2.20
4.0	2.22	2.33	2.49	2.65
5.0	2.45	2.60	2.78	3.04
6.0	2.60	2.70	3.04	3.33
7.0	2.75	2.95	3.23	3.57
8.0	2.80	3.03	3.37	3.76
9.0	2.88	3.11	3.48	3.92
10.0	2.92	3.17	3.56	4.04
12.0	2.97	3.24	3.68	4.22
14.0	3.00	3.28	3.75	4.34

Forces Acting on Pipes

Embankment conditions: $w = c_p \gamma D^2$

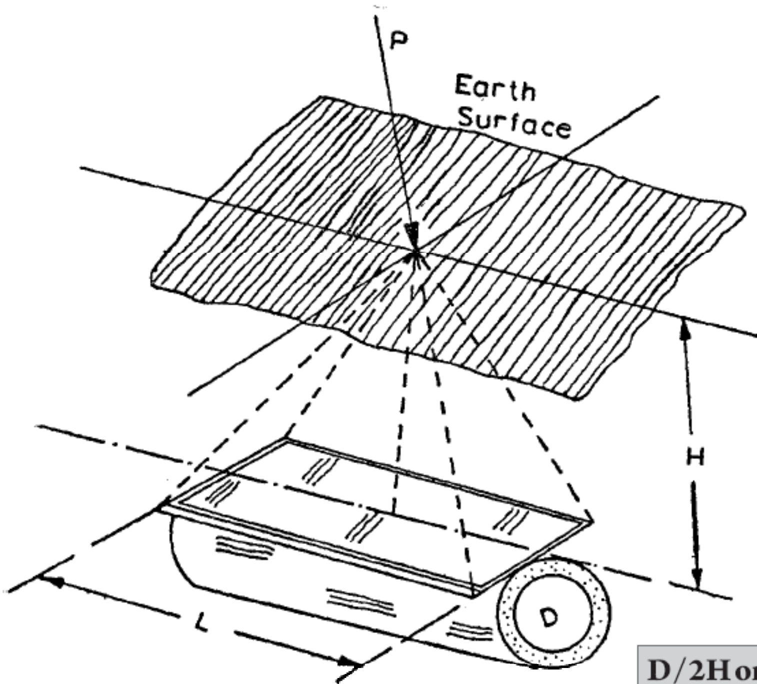


w = load (pound per foot)
γ = specific weight (pounds per cu.ft)
c_p = load calculation coefficient

Table 4.2 Values of the coefficient c_p for **Eq.** 4.10

$\frac{\text{Cover depth}}{\text{pipe diameter}} = H/D$	Rigid pipe, Unyielding base noncohesive backfill	Flexible pipe average conditions
1.0	1.2	1.1
2 0	2.0	2.6
[illegible].0	4.0	4.0
4.0	6.7	5.4
6.0	11.0	8.2
8.0	16.0	11.0

Forces due to Superimposed Loads



Concentrated loads:

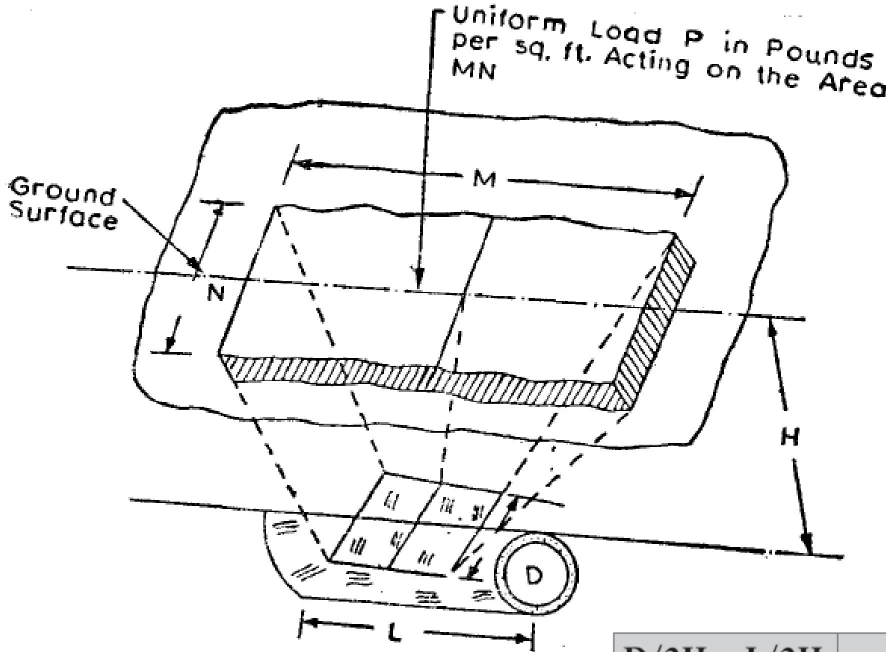
$$w = c_1 P(I / L)$$

Impact factor,
I = 1.50 (highways),
1.75 (Railways),
1.00 (Airfields)

C_1 values Table

D/2H or L/2H	M/2H or L/2H									
	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.5	2.0	5.0
0.1	0.019	0.037	0.053	0.089	0.103	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.109	0.252	0.203	0.219	0.229	0.238	0.244	0.248
0.4	0.067	0.131	0.190	0.320	0.373	0.405	0.425	0.440	0.454	0.460
0.6	0.089	0.174	0.252	0.428	0.499	0.544	0.572	0.596	0.613	0.460
0.8	0.103	0.202	0.292	0.499	0.584	0.639	0.674	0.703	0.725	0.740
1.0	0.112	0.219	0.318	0.544	0.639	0.701	0.740	0.773	0.800	0.816
1.2	0.117	0.229	0.333	0.572	0.674	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.596	0.703	0.774	0.820	0.961	0.894	0.916
2.0	0.124	0.244	0.355	0.613	0.725	0.800	0.849	0.896	0.930	0.956

Forces due to Superimposed Loads



Distributed loads:

$$w = c_1 pID$$

C$_1$ values Table

D/2H or L/2H	M/2H or L/2H									
	0.1	0.2	0.4	0.6	0.8	1.0	1.2	1.5	2.0	5.0
0.1	0.019	0.037	0.053	0.089	0.103	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.109	0.252	0.203	0.219	0.229	0.238	0.244	0.248
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2.0	0.124	0.244	0.355	0.613	0.725	0.800	0.849	0.896	0.930	0.956

Impact factor,
I = 1.50 (highways),
1.75 (Railways),
1.00 (Airfields)

Problems

Problem 1: What is the probable maximum load on a pipe laid in a trench that is 3.5 ft wide if the depth of the fill above the top of the pipe is 9 ft and the filling material is wet sand? (unit weight of sand = 120 lb/cu. Ft)

Problem 2: A 3 ft diameter steel pipe is buried on a trench 4 ft wide. The backfill is clay (γ = 120 lb/cu ft) and the top of the pipe is 6 ft below the surface of the fill. Calculate the total load on the pipe. Take the value of c as 1.2.

Pipe Laying Operation

- ❑ Preparation of detailed plans of roads and streets
- ❑ Locating the proposed alignment on the ground
- ❑ Excavating trenches
- ❑ Preparation of the bottom of the trench excavated
- ❑ Lowering of pipes into the trench
- ❑ Laying of pipes
- ❑ Jointing pipes
- ❑ Anchoring of pipes
- ❑ Back filling the trench with excavated material
- ❑ Pipe testing

Common Problems in Conveyance Systems

High head loss in conduits requiring excessive pumping heads:

- partially closed valve
- air accumulation at high points
- excessive growth of slime, scale formation in pipe interior

Excessive loss of water

- leakage
- unauthorized connections

Corrosion in pipes

- aggressive water

O&M of Conveyance Systems

Maintain record of pumping head vs. flow: this will provide an indication of pipeline deterioration

Regular inspection:

- illegal or unauthorized connections
- right of way encroachments
- construction activity near pipelines
- slime growth in pipes
- leaks
- damaged structures

Check operation of air-release and vacuum valves

Inspect pipe interiors:

- slime accumulation
- deterioration of lining materials

Reading Materials for this Lecture

Water Supply Engineering (by M. A. Aziz)

Chapter 9: Water and Environmental Engineering (by H. Rahman and A. A. Muyeed)

Chapter 7: Water Works Engineering (by Qasim and co-authors)
[photocopy of the chapter provided in class]

Week-(10)

MD Ehasan Kabir

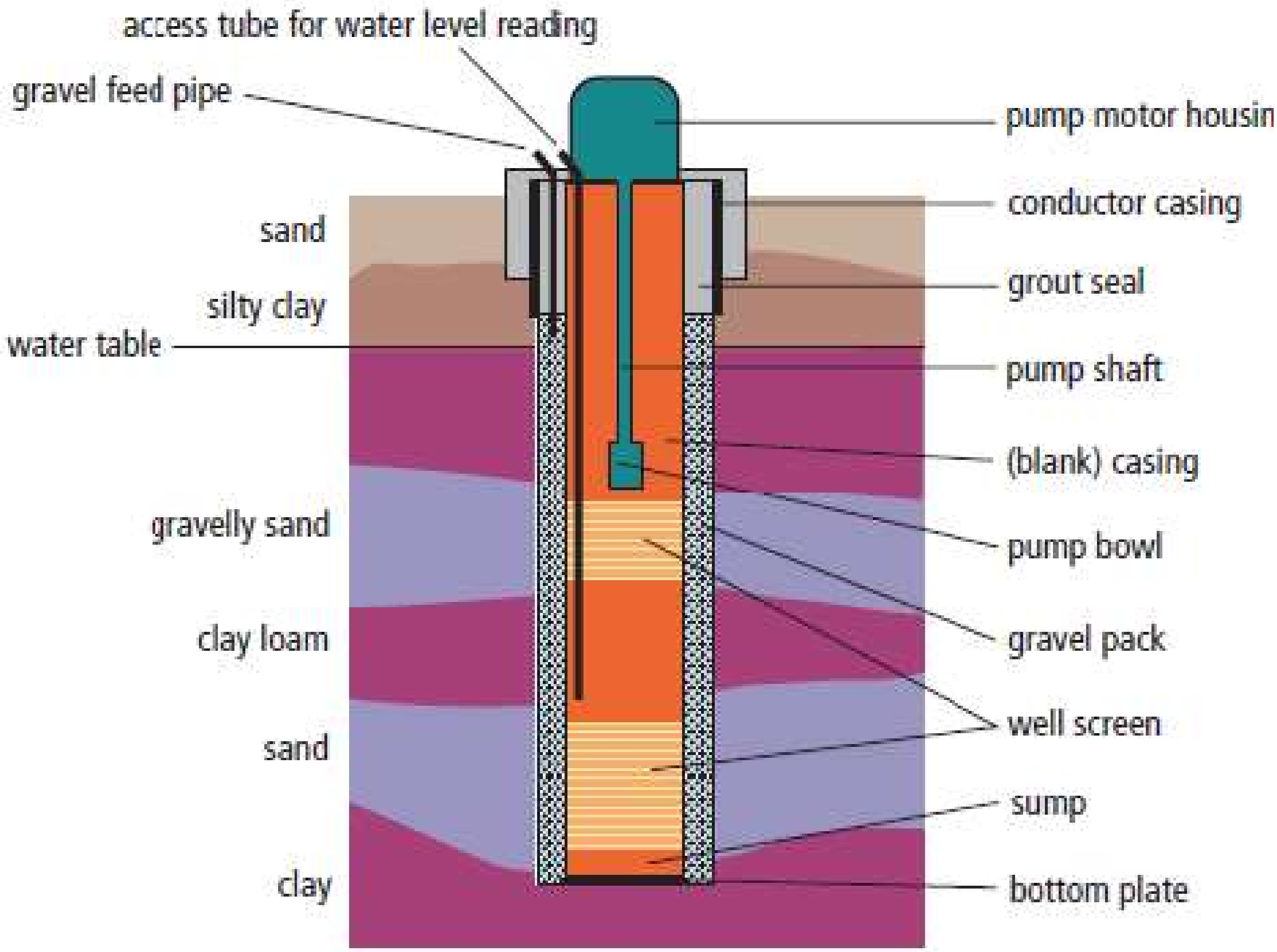
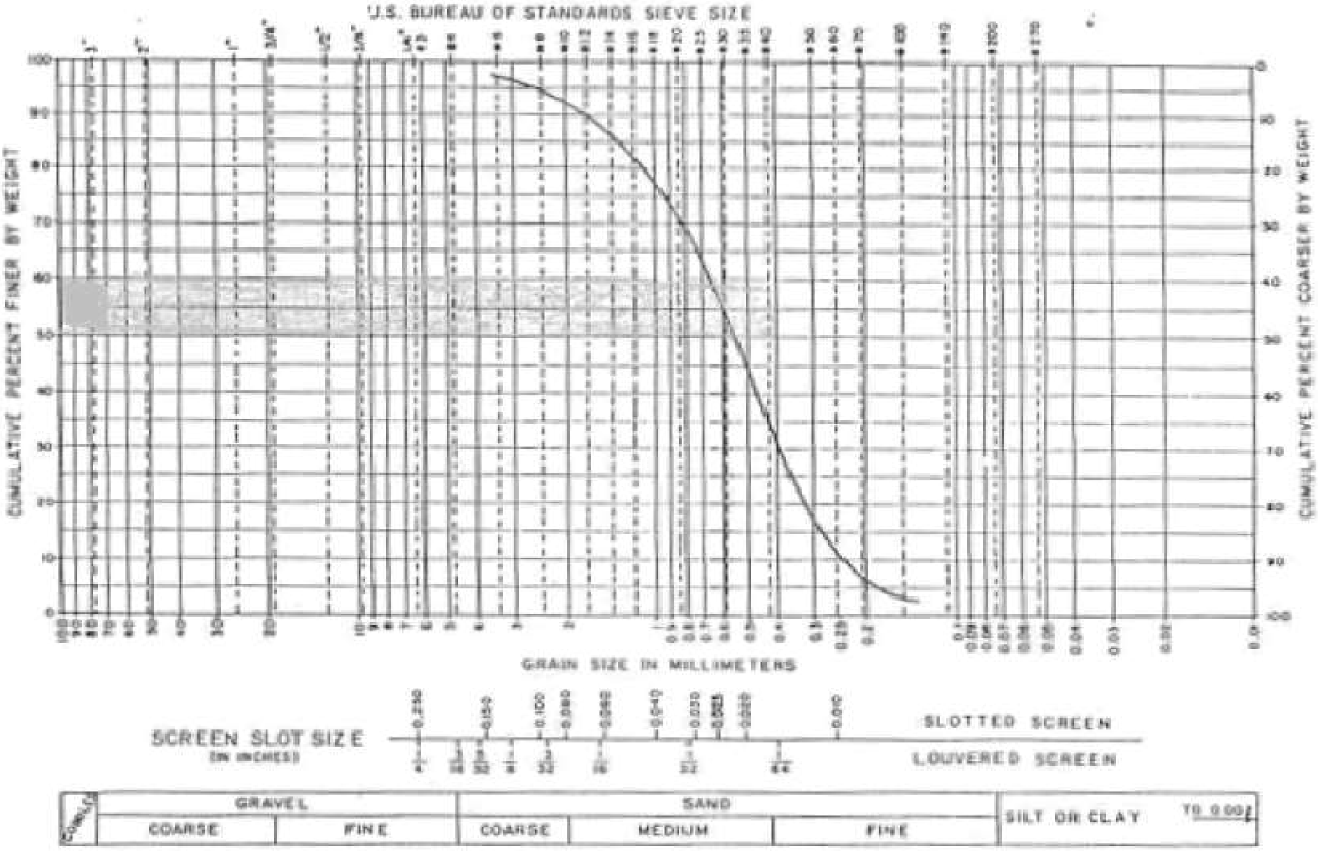
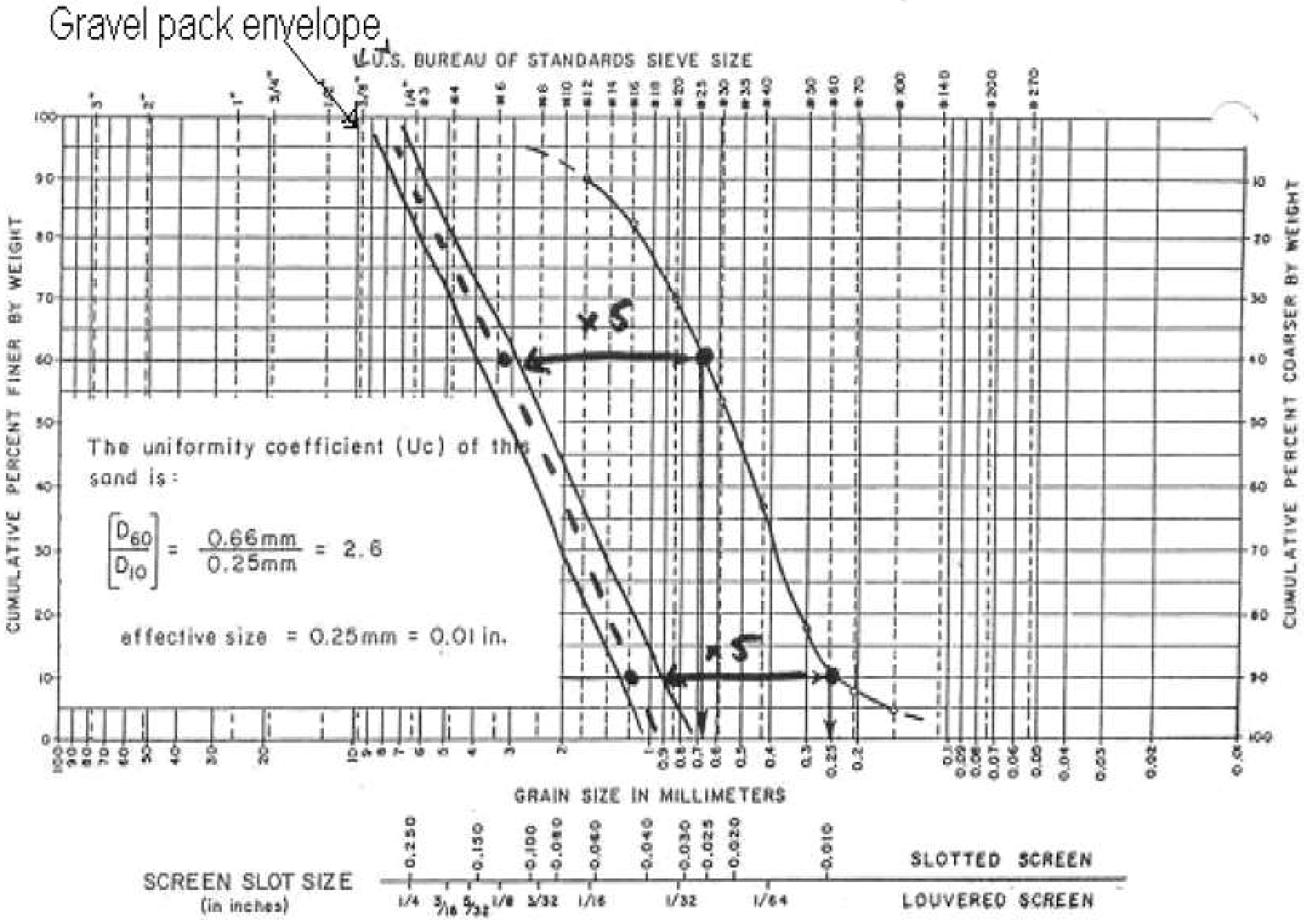
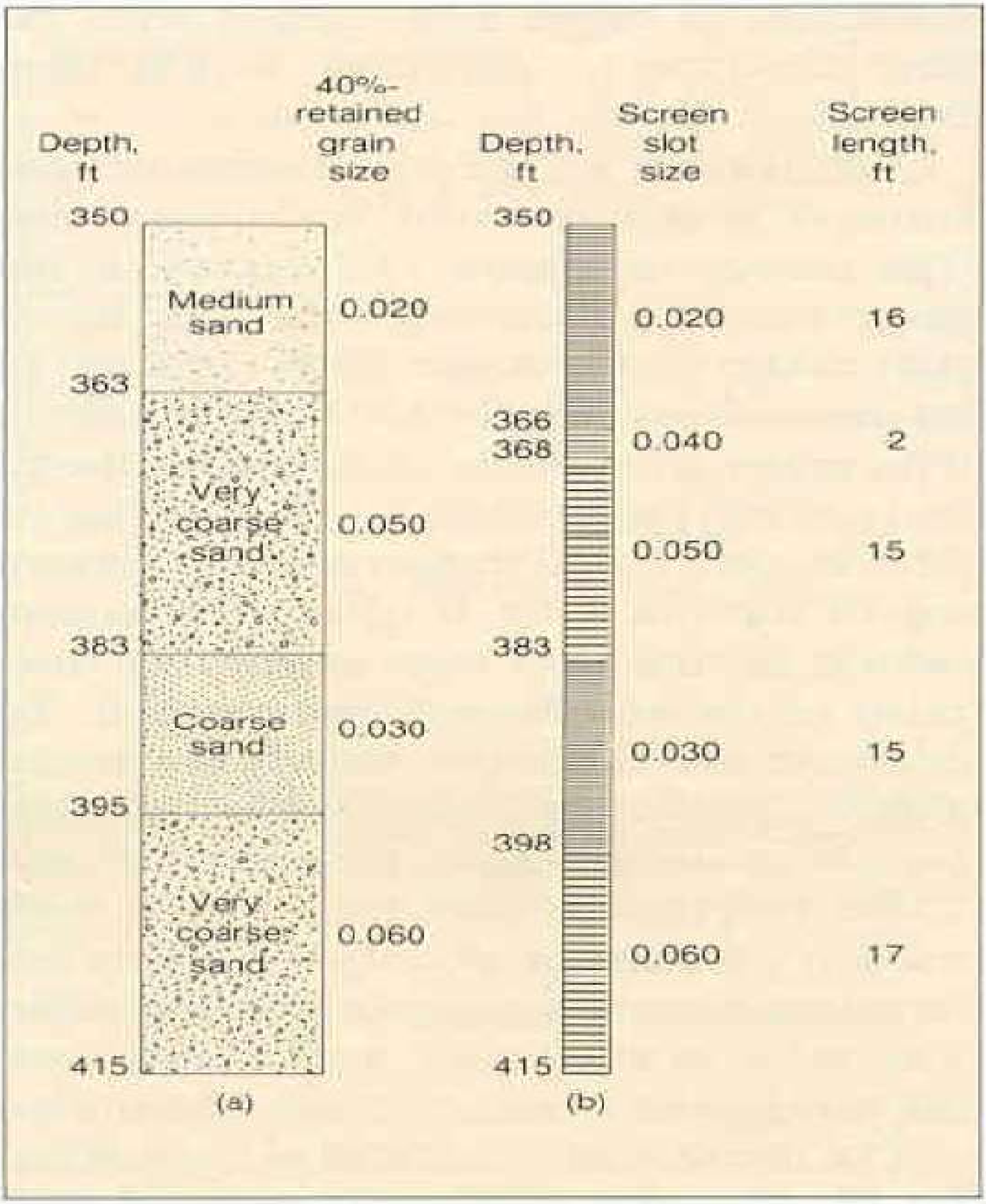


Figure 1. Components of a well.


U.S. BUREAU OF STANDARDS SIEVE SIZE
CUMULATIVE PERCENT FINER BY WEIGHT
CUMULATIVE PERCENT COARSER BY WEIGHT
GRAIN SIZE IN MILLIMETERS
SCREEN SLOT SIZE
(IN INCHES)
SLOTTED SCREEN
LOUVERED SCREEN
GRAVEL
SAND
COARSE
FINE
COARSE
MEDIUM
FINE
SILT OR CLAY
TO 0.002



Gravel pack envelope
U.S. BUREAU OF STANDARDS SIEVE SIZE
CUMULATIVE PERCENT FINER BY WEIGHT
CUMULATIVE PERCENT COARSER BY WEIGHT
x5
x5
The uniformity coefficient (Uc) of this sand is:
[D60]/[D10] = 0.66mm/0.25mm = 2.6
effective size = 0.25mm = 0.01 in.
GRAIN SIZE IN MILLIMETERS
SCREEN SLOT SIZE (in inches)
SLOTTED SCREEN
LOUVERED SCREEN



Depth, ft
40%-retained grain size
350
Medium sand
0.020
363
Very coarse sand
0.050
383
Coarse sand
0.030
395
Very coarse sand
0.060
415
(a)
Depth, ft
Screen slot size
Screen length, ft
350
0.020
16
366
368
0.040
2
0.050
15
383
0.030
15
398
0.060
17
415
(b)

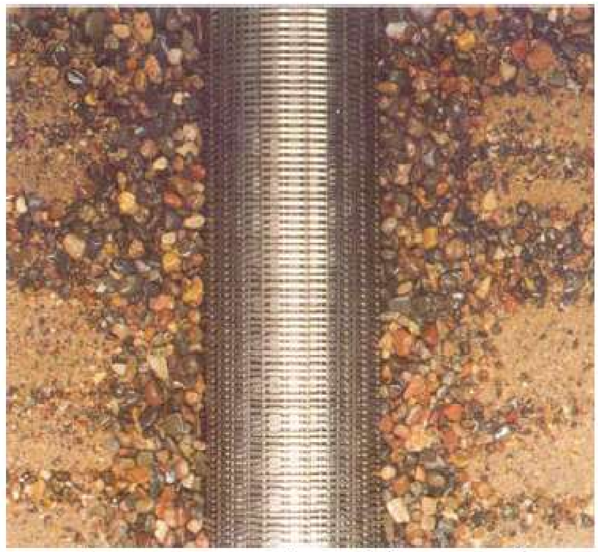


Figure 5.12 Natural development removes most particles near the well screen that are smaller than the slot openings, thereby increasing porosity and hydraulic conductivity in a zone surrounding the screen.

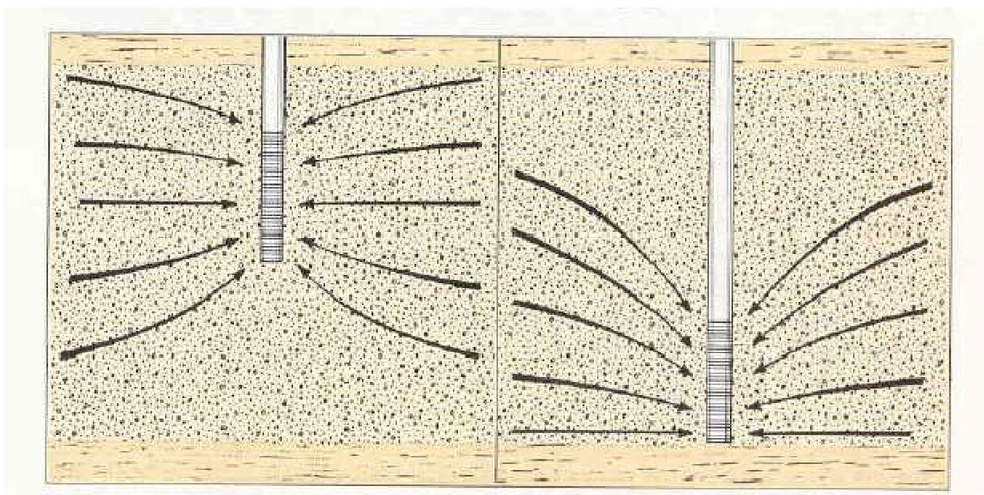
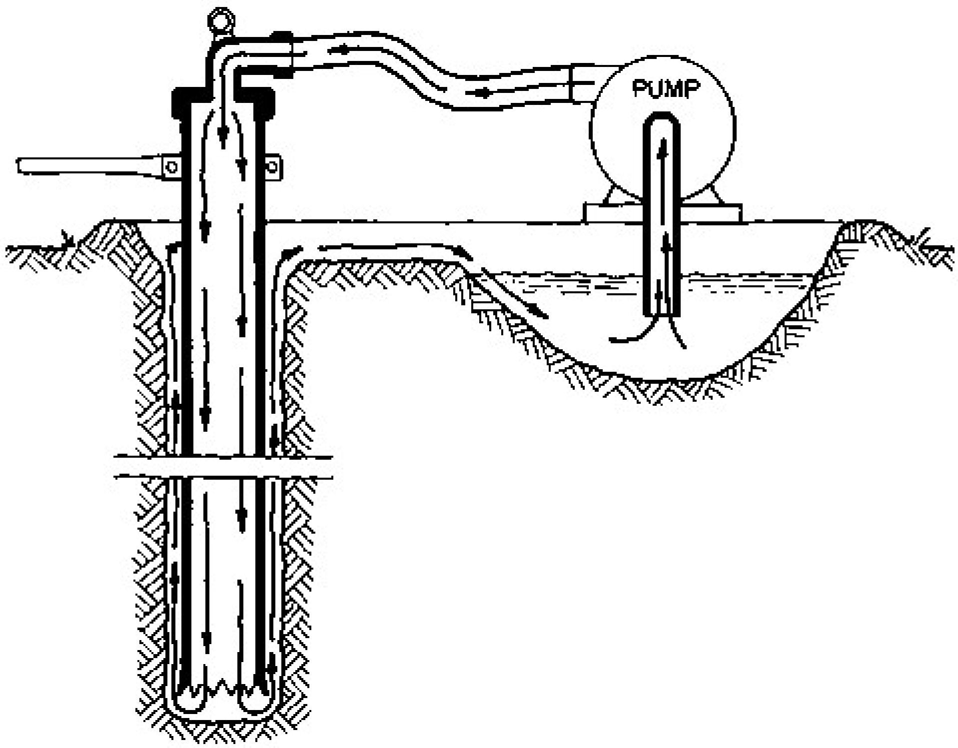
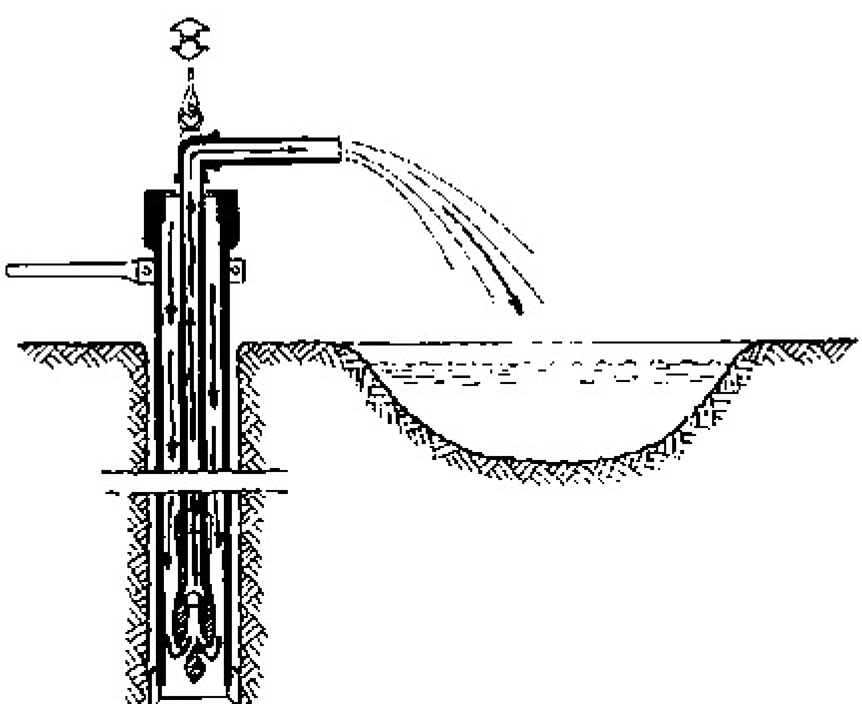


Figure 5.3 partial penetrations when the intake portion of the well is less than the full thickness of the aquifer. This causes distortion of the flow lines and greater head losses.


PUMP



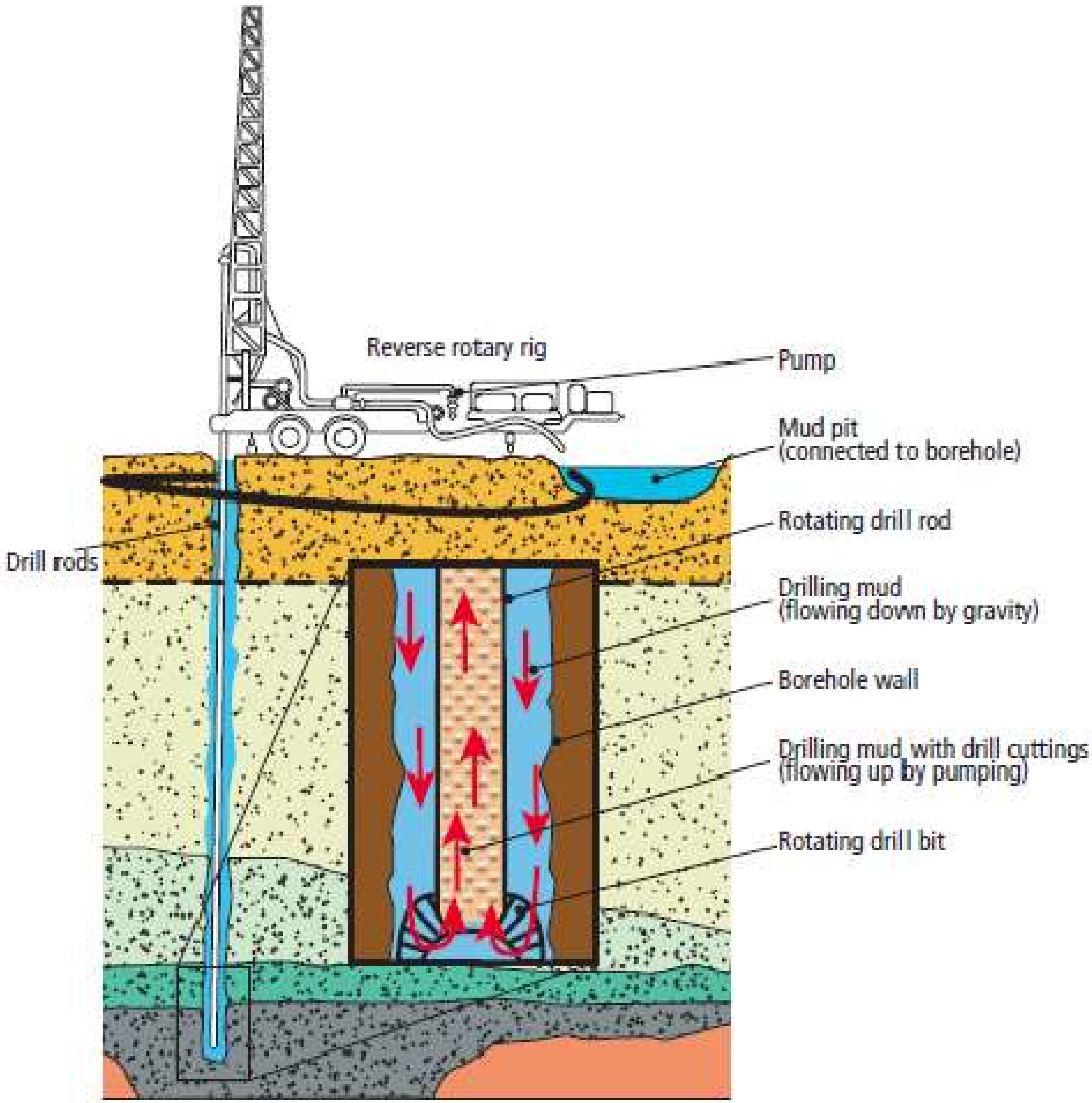
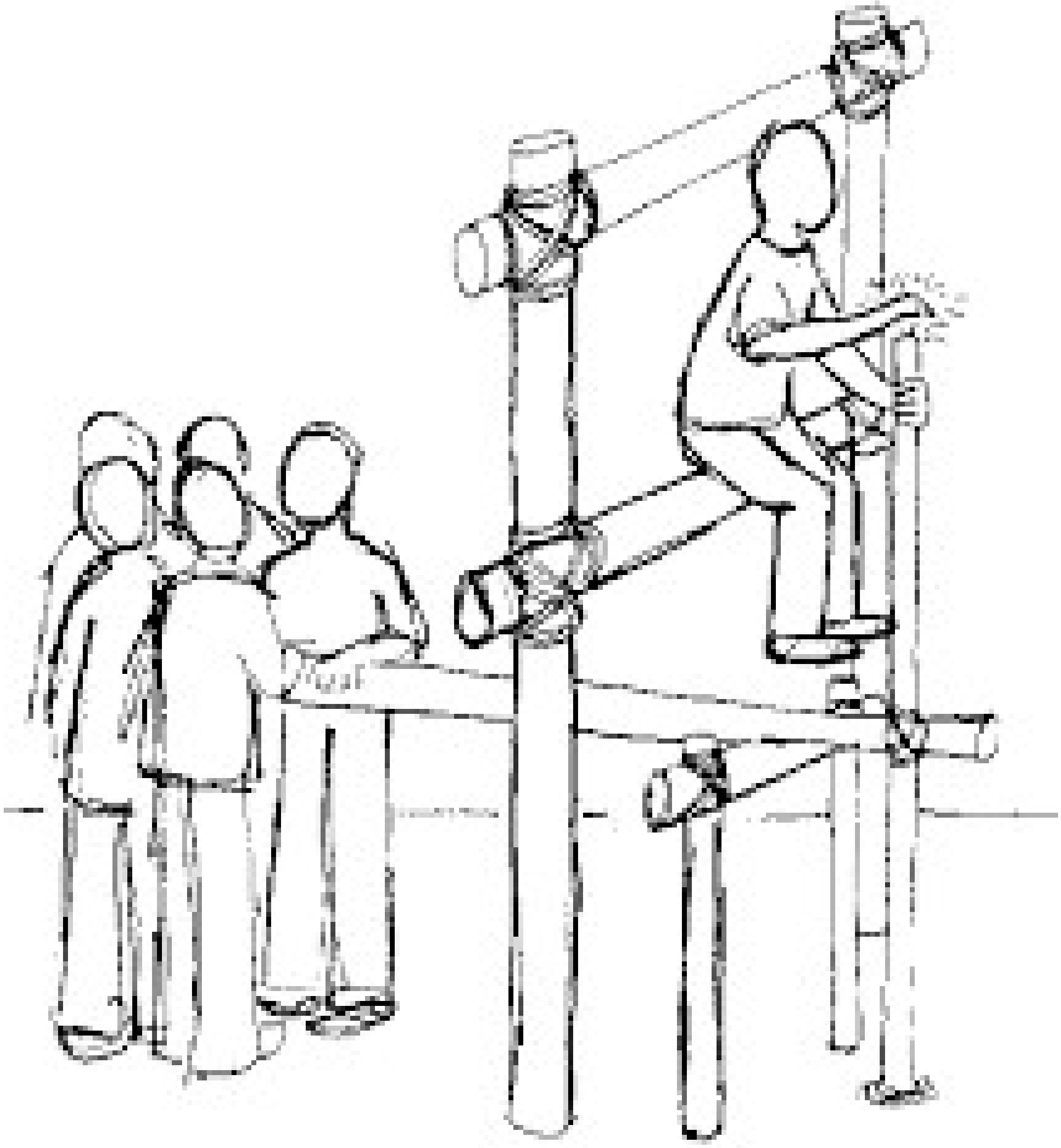


Figure 2. Principles of reverse rotary drilling. (adapted from Driscoll, 1996. Johnson Screens/A Wetherford Company is publisher and copyright holder.)



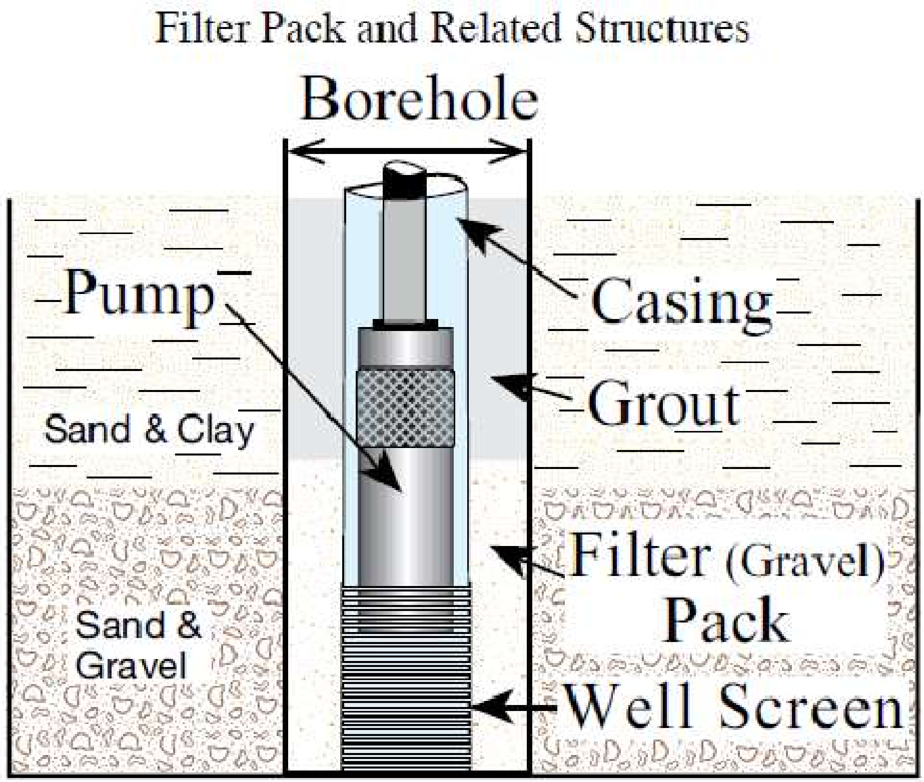
Penn State **Extension**

Setting Up the Drill Rig

WELL DEVELOPMENT

After the well screen, well casing, and gravel pack have been installed, the well is *developed* to clean the borehole and casing of drilling fluid and to properly settle the gravel pack around the well screen. The three most common methods used are overpumping, surging, and jetting. A typical method for well development is to surge or jet water or air in and out of the well screen openings. This procedure may take several days or perhaps longer, depending on the size and depth of the well. A properly developed gravel pack keeps fine sediments out of the well and provides a clean and unrestricted flow path for ground water.

WELL AND WELLHEAD PROTECTION



The construction of the final well seal is intended to provide protection from leakage and to keep runoff from entering the wellhead (Figure 3). Minimum standards for surface seals have been set by the California.

Figure 3: Properly completed well with elevated concrete seal

1. Given Sieve Analysis Data:

Sieve Number	Material Retained (gm)
30	0.6
40	7.8
50	27.7
100	37.3
200	15.4
Pan	11.2

Total=100gm

Solution:

Draw particle size distribution curve.

Calculate D10=0.07 mm, D60=0.34 mm, U=4.86

Hence, design gravel pack well

Draw the 2^{nd} curve and from that curve,

Calculate D10=0.54 mm, D60=1.05 mm, U=1.95,

So, from this curve, calculate Slot size=0.54 mm = 0.021 inch,

Hence **Slot No. is 21**

Assume minimum opening area=15% for 100mm=4inch diameter well strainer

Yield= (π x 4/12 x 0.15 x0.1 x 3600 x 7.48) / 2.5 = **169 US gallon/hr/ft of strainer**.

Gravel packs material:

Sieve Number	Sieve Size (mm)	Cumulative % retained
4	4.76	--
8	2.36	0 – 8
12	1.68	0 – 14
16	1.20	20 – 36
20	0.84	54 – 70
30	0.60	76 – 92
40	0.42	92 – 100

Fluoride Removal

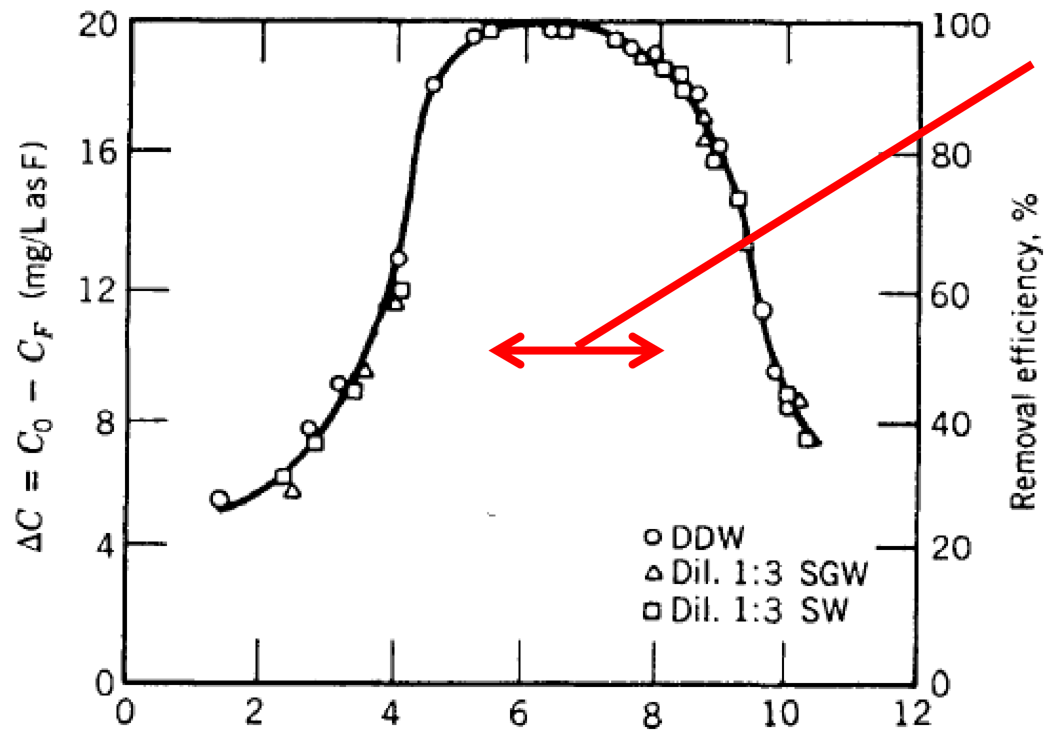
Removal by Ion Exchange using Activated Alumina

Factors affecting removal by Activated Alumina

Other removal techniques (Lime Softening and Alum Coagulation)

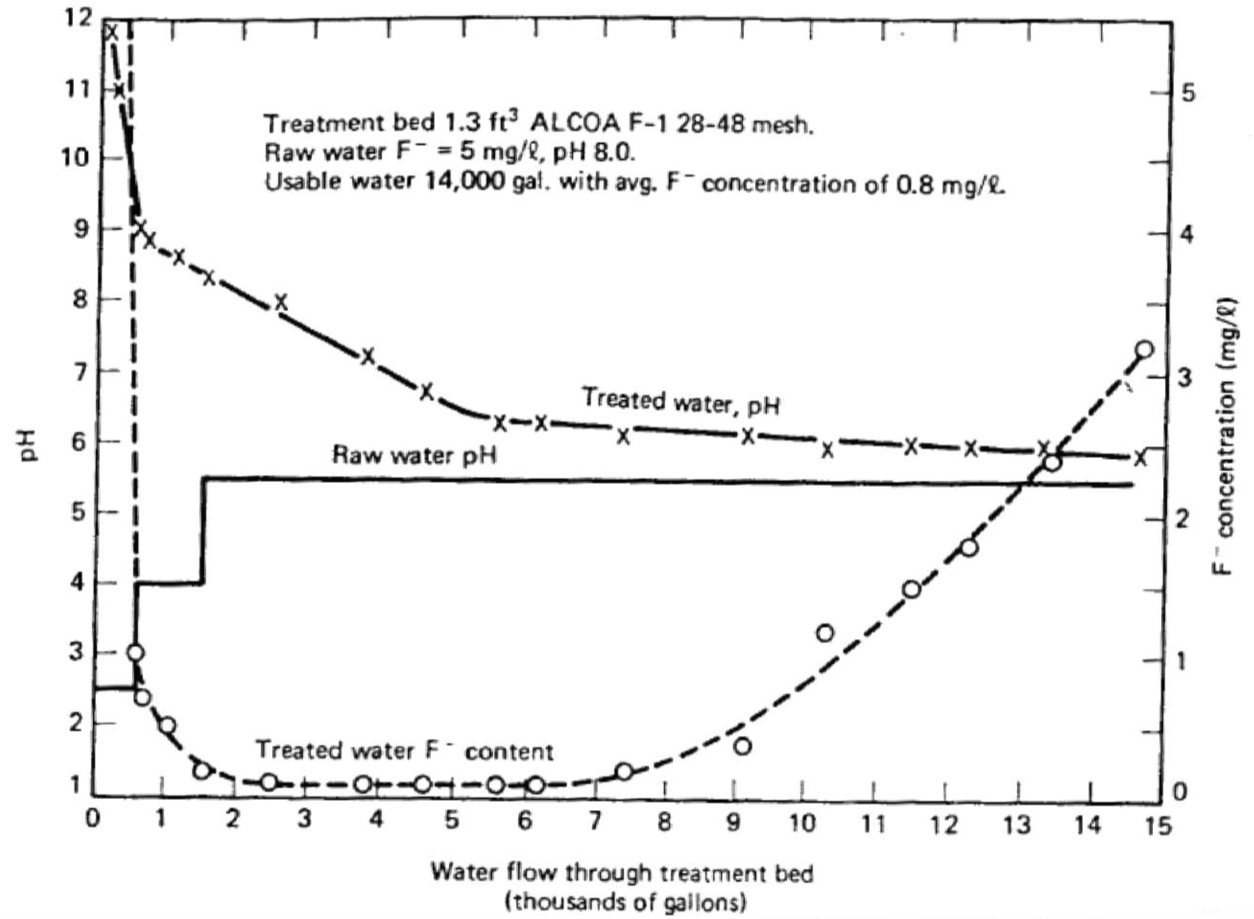
Removal by Activated Alumina

- Activated Alumina is a granular, highly porous material (consisting of Al_2O_3) and Fluoride is removed as a result of **ion exchange**
- Activated Alumina can be regenerated with NaOH
- Optimum removal of Fluoride is pH-dependent



Removal by Activated Alumina

- Steps taken to elute the Fluoride from Activated Alumina
  - (a) Backwash (10 – 15 min)
  - (b) Regeneration (1 – 1.5 hr, 0.25 – 3 gpm/ft3, 0.5 – 2% NaOH)
  - (c) Neutralization (using pH adjusted raw water)



Other removal techniques: Lime Softening

By forming an insoluble precipitate and by coprecipitation with $Mg(OH)_2$

$$Ca(OH)_2 + 2HF \rightarrow CaF_2\downarrow + 2H_2O$$

To estimate the magnesium required, Culp et al. developed this equation:

$$F_{residual} = F_{initial} - (0.07F_{initial} \times \sqrt{Mg}$$

Problems:

- Low solubility of CaF_2 (10 mg/L at pH 10)
- Large amounts of Magnesium required (100 mg/L to reduce Fluoride from 5 to 1.5 mg/L)
- Large amounts of sludge produced

Other removal techniques: Alum Coagulation

By adsorption on to Al(OH)3 particles, which is formed from the reaction between alum and alkalinity of water:

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4 + 14H_2O + 6CO_2$$

Problems:

- Large amounts of Alum required (250 mg/L to reduce Fluoride from 3.6 to 1.4 mg/L)
- Large amounts of sludge produced

Week-(11)

MD Ehasan Kabir

Adsorption

Adsorption process/kinetics

Mechanisms of Adsorption

Factors affecting adsorption process

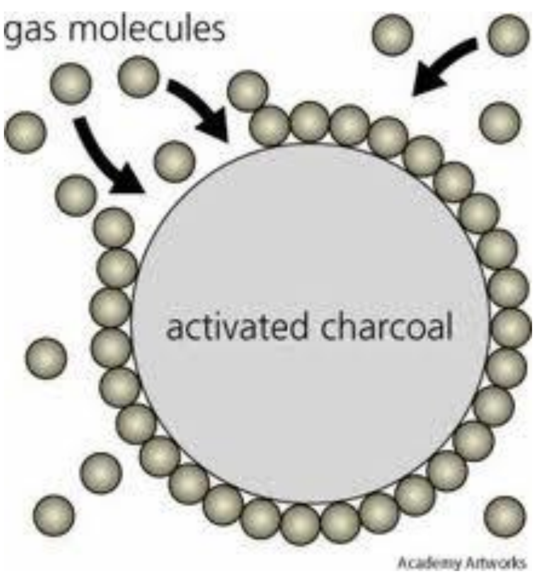
Adsorption Isotherms

What is adsorption?

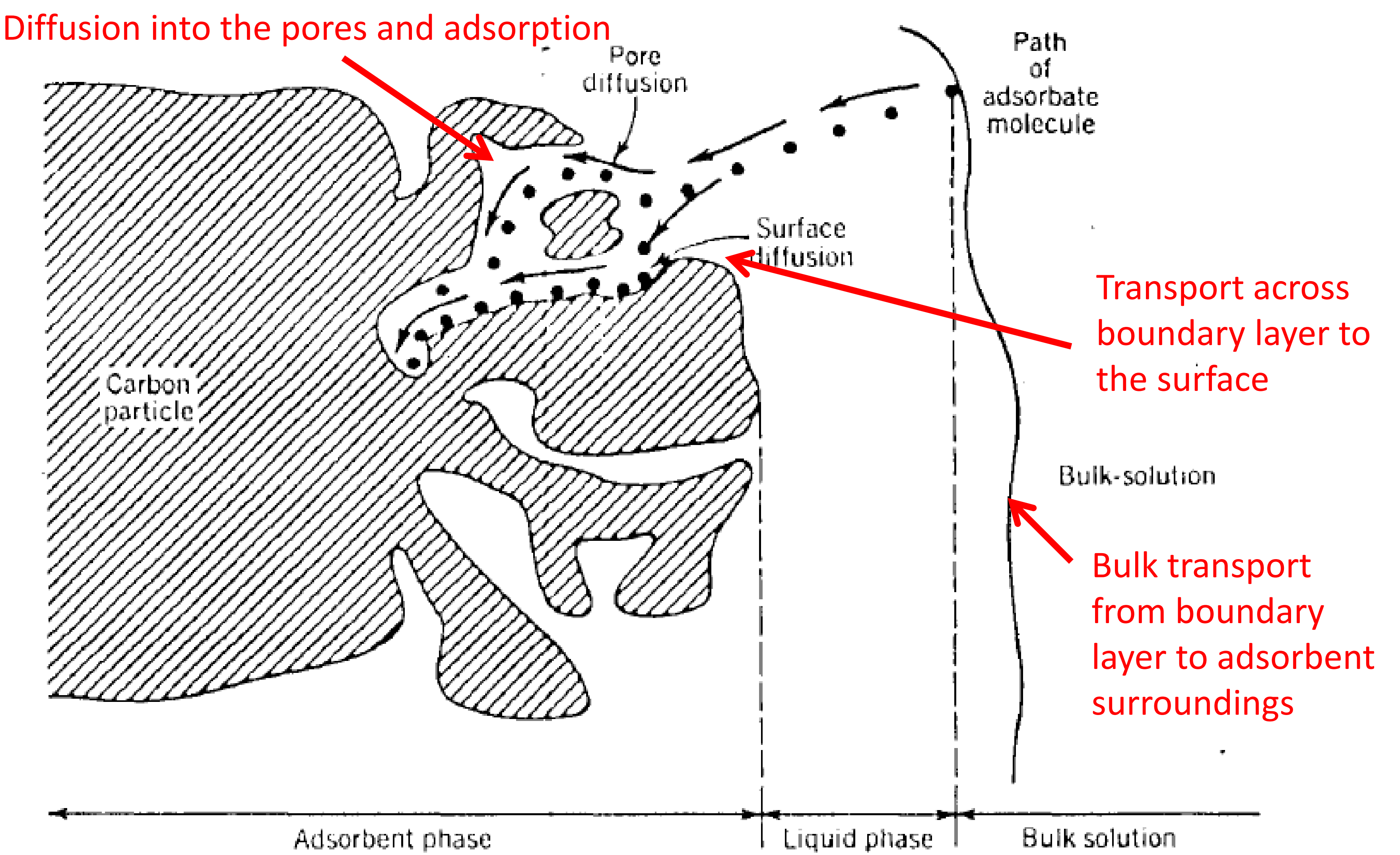
The physical and/or chemical process in which a substance is accumulated at the interface between the phases which may be solid-liquid, liquid-liquid, gas-liquid or gas-solid.

<u>Adsorbate:</u> the substance being removed from the liquid phase

<u>Adsorbent:</u> the solid phase onto which the accumulation takes place. <u>Activated carbon</u> is used exclusively in full scale water treatment.



Kinetics of adsorption



Mechanisms of adsorption

Adsorbate has less free energy on the surface of adsorbent than in solution.

Physical adsorption: dipole-dipole interaction, hydrogen bonding, Van der Waal's force, Hydrophobic bonding (non-polar adsorbate)

Typical for water treatment (e.g. adsorption of fatty acids on carbon)

Chemisorption: Electrostatic chemical bonding between adsorbate and adsorbent

$$ROH(aq) + SOH = SOR + H_2O\ (aq)$$

R is metal ion adorbate and S is metal oxide adsorbent

Mechanisms of adsorption

Adsorption of Electrolytes: Adsorption of ionic species to surfaces by electrostatic attraction.

Highly dependent on pH and ionic strength.

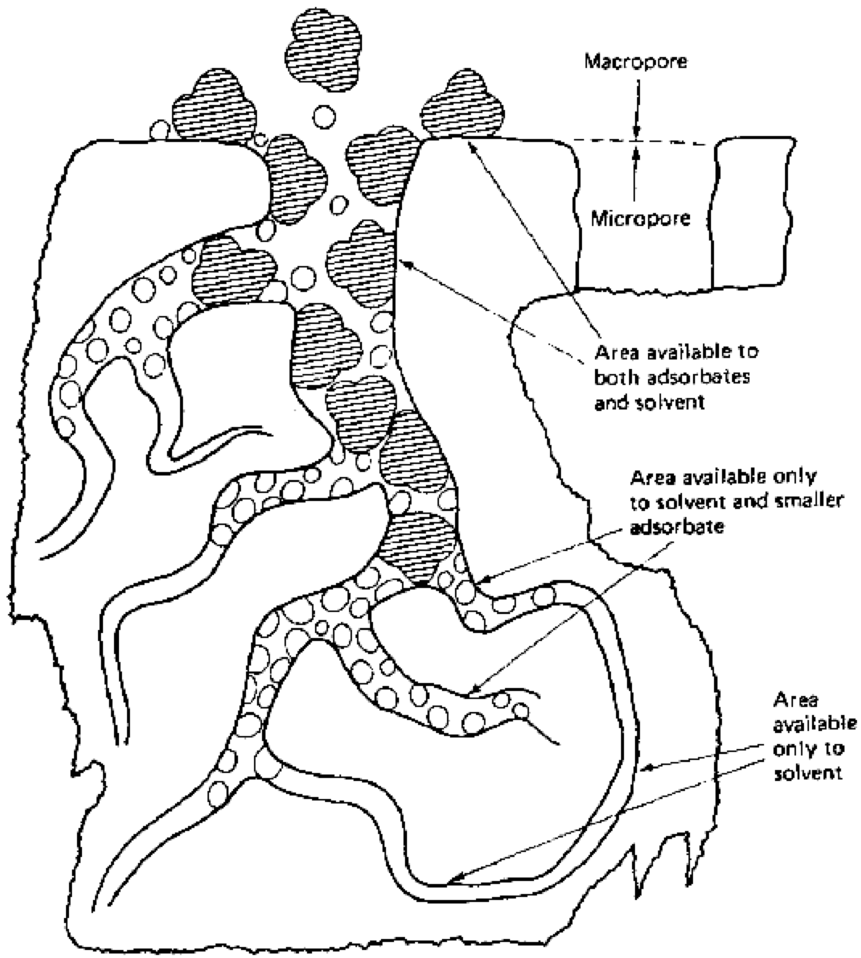
pH governs the stability of acids and bases in polar water

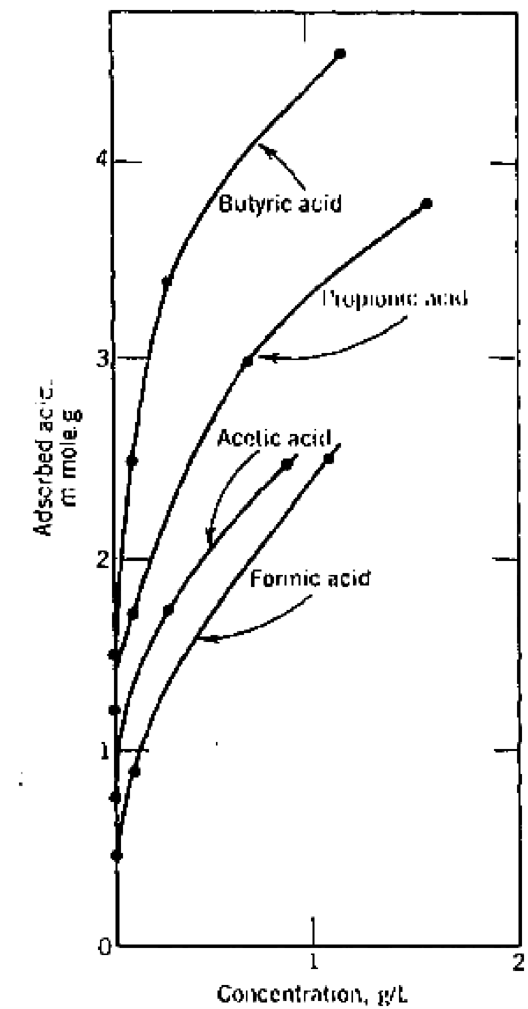
- Covalent or electrostatic chemical bonding
- Dispersion interactions (Van der Waals force) and hydrogen bonding
- Dipole-dipole interaction

Increasing bond energy

Factors affecting adsorption process

(a) Agitation (b) Characteristics of the Adsorbent (c) Solubility of the Adsorbate (d) Size of Adsorbate Molecules (e) pH (f) Temperature

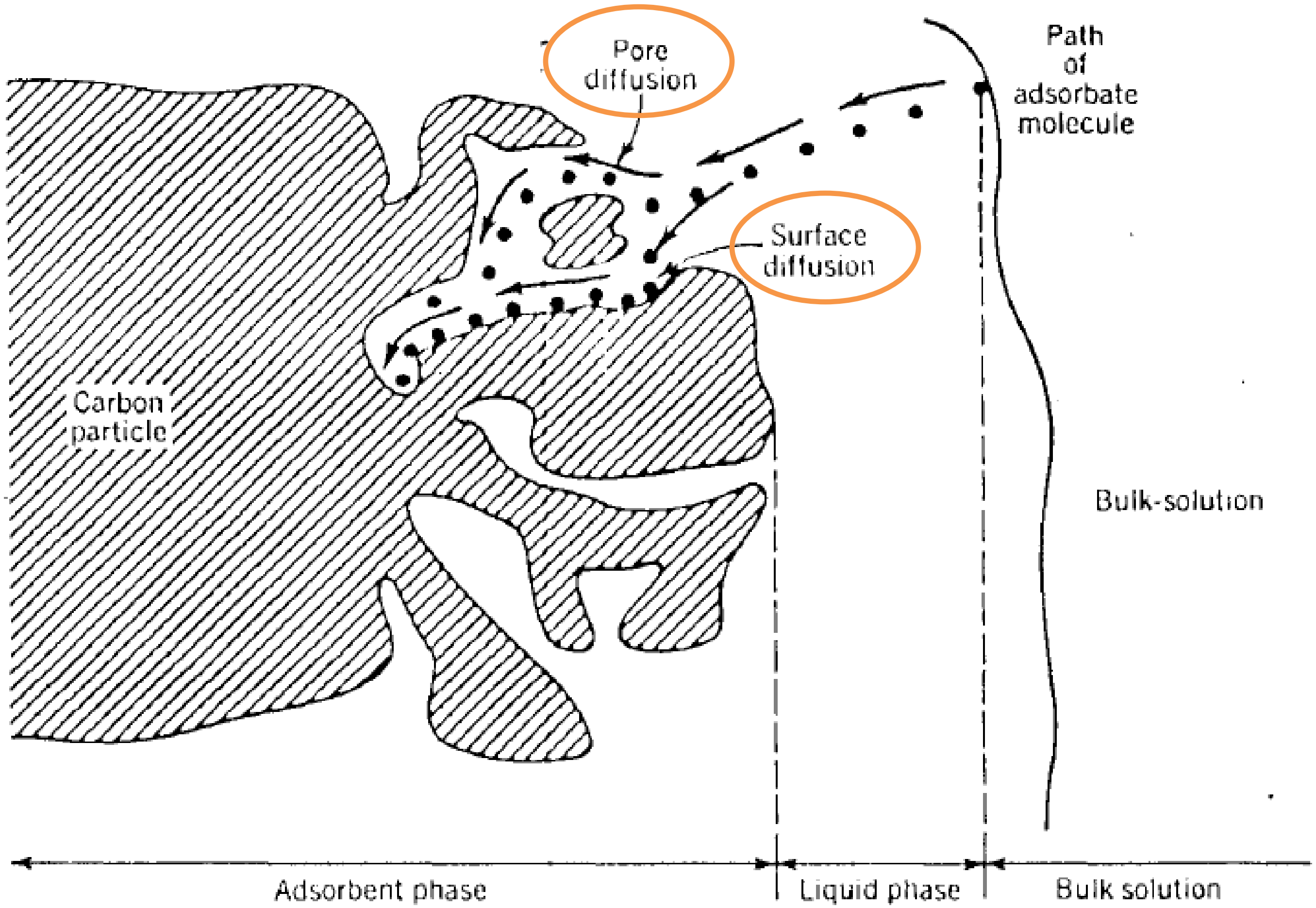




Factors affecting adsorption process

(a) Agitation :

Surface diffusion will be rate-limiting when little agitation occurs
Pore diffusion will be rate-limiting in a highly agitated system



Factors affecting adsorption process

(b) <u>Characteristics of the Adsorbent:</u>

Particle size ↓, rate of adsorption↑

(PAC has faster adsorption rate than GAC)

(c) <u>Solubility of Adsorbate:</u>

Typically, Solubility↓,

adsorption capacity↑

(d) <u>Size of Adsorbate:</u>

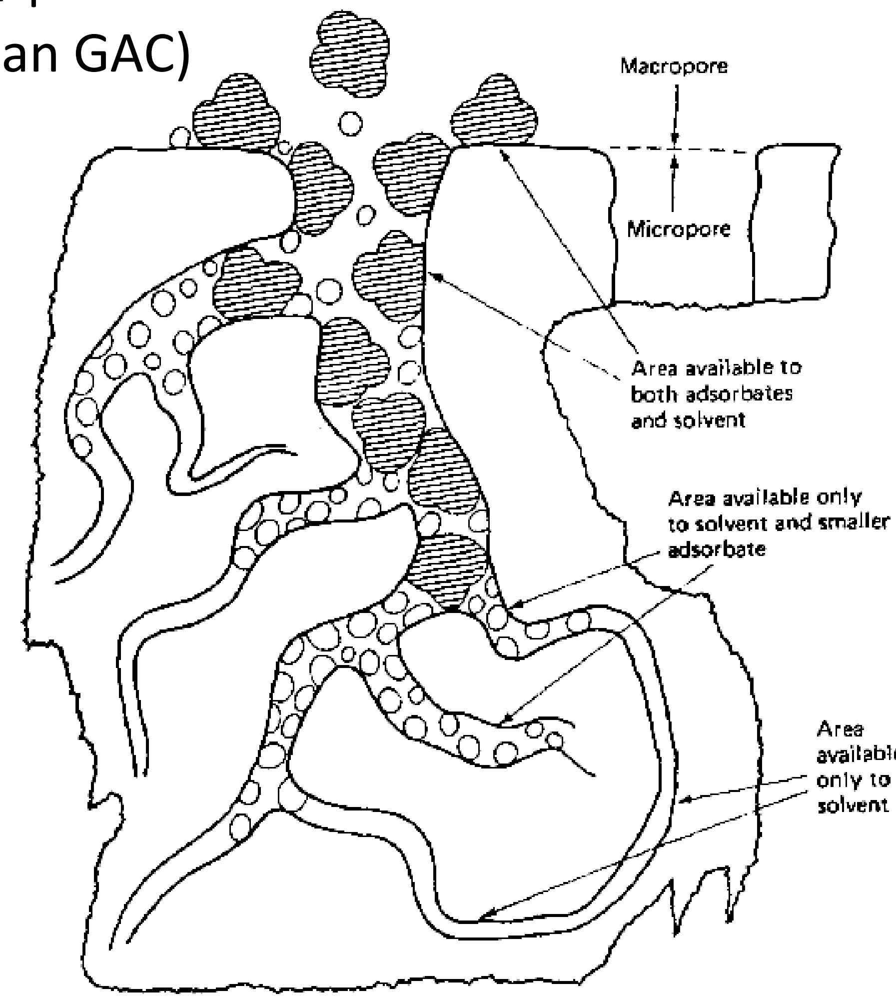
Size of particles ↑,

adsorption capacity↑

(e) <u>Temperature:</u>

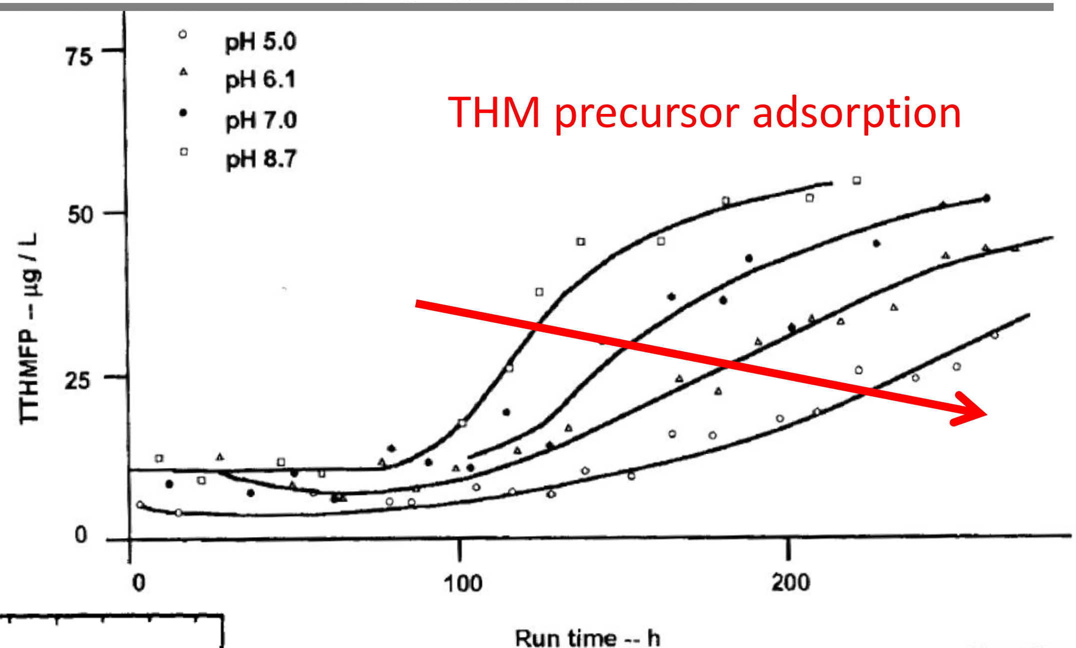
Temperature↑,

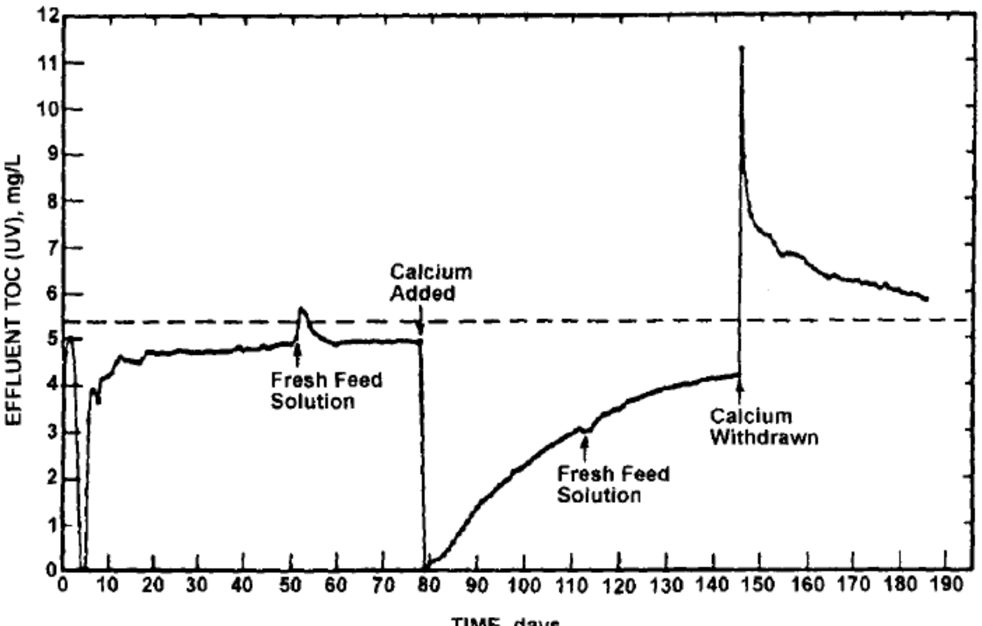
adsorption rate↑



Factors affecting adsorption process

(f) <u>pH:</u>
pH affects dissociation of electrolytes (non electrolytes not affected)





(g) <u>Effect of foreign ions:</u>
(e.g. Effect of $CaCl_2$ on fulvic acid adsorption)

Physical Properties of Activated Carbon

PAC : (filterability and bulk density)

- filterability → Product water contamination
- bulk density → Removal capacity of the adsorbate

GAC: (hardness and particle size)

- hardness → Losses by attrition in filter runs and backwashing
- particle size → Affects bulk transport (availability of macropores) and headloss across the beds

Other properties affecting adsorption for activated carbon:

- ❑ Specific surface area (GAC has an upper limit of 1500 m^2/g)
- ❑ Pore size distribution
- ❑ Chemical nature of the surface

The Adsorption isotherm

Specifies the equilibrium surface concentration of adsorbate as a function of bulk concentration of adsorbate in solution

Different types of isotherms

(a) Langmuir isotherm (adsorbed layer one molecule thick)

(b) Freundlich isotherm (Heterogeneous adsorbent surface with different adsorption sites)

(c) Brunauer, Emmett and Teller (BET) isotherm (molecules can be adsorbed more than one layer thick)

Adsorption tests are carried out at constant temperature to construct adsorption isotherms.

Langmuir Isotherm

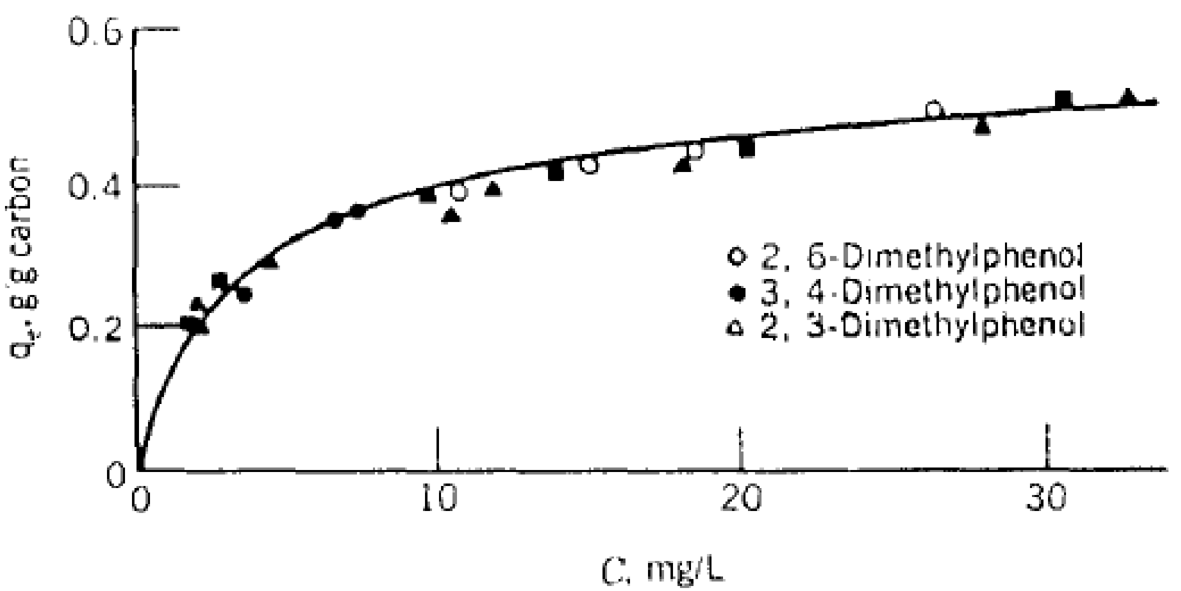
$$\frac{q}{Q} = \frac{bC}{1 + bC}$$

q = the number of moles of adsorbate/adsorbent mass

Q = maximum number of moles adsorbed / adsorbent mass when surface sites are saturated

C = equilibrium molar concentration of adsorbate in solution

b = empirical constant

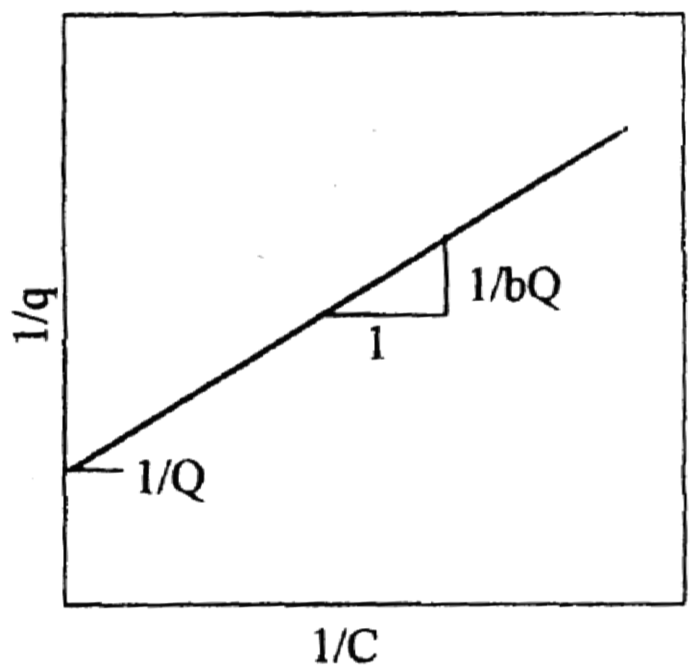


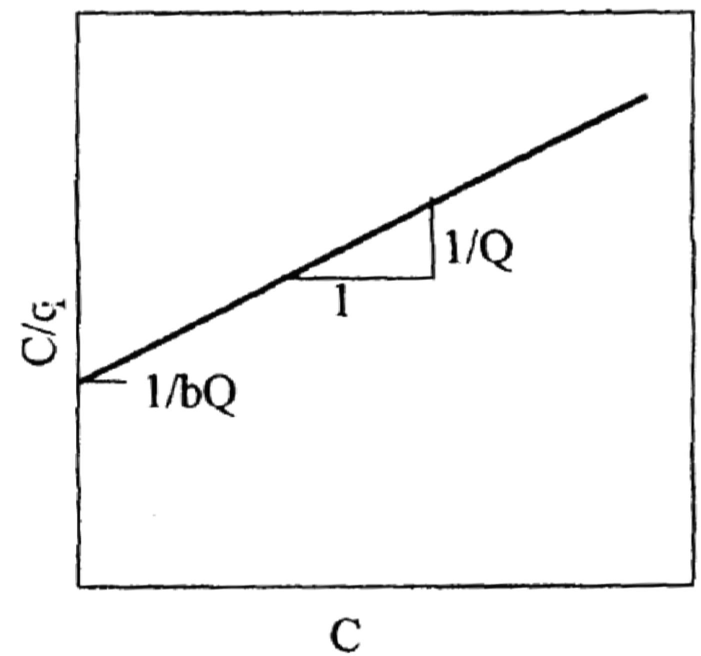
Langmuir Isotherm

$$\frac{q}{Q} = \frac{bC}{1 + bC}$$

$$\frac{C}{q} = \frac{1}{bQ} + \frac{C}{Q}$$

$$\frac{1}{q} = \frac{1}{bQ}\frac{1}{C} + \frac{1}{Q}$$

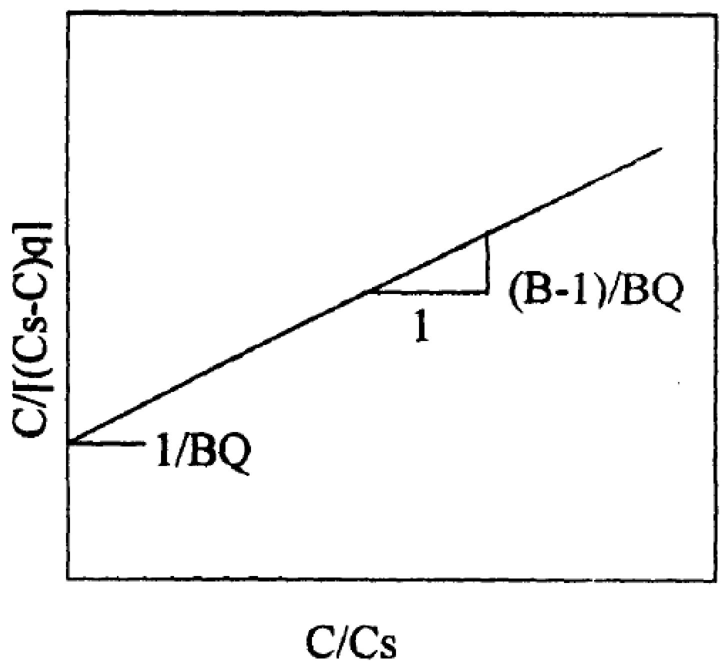


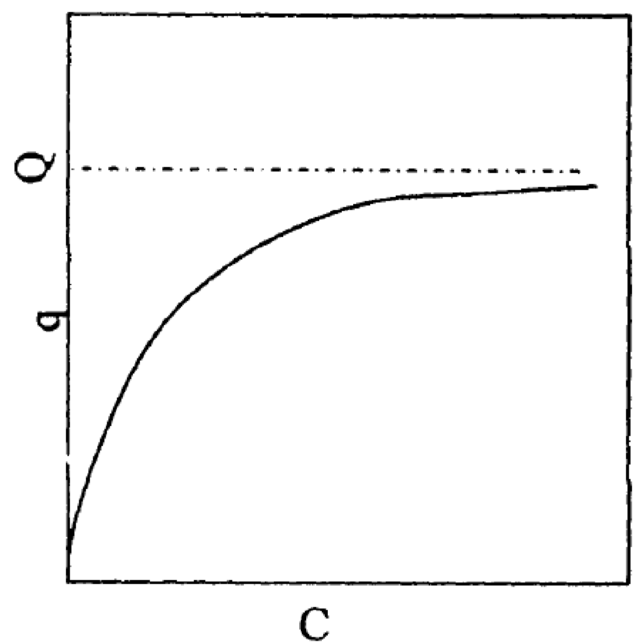


BET Isotherm (multi-layer adsorption)

$$\frac{q}{Q} = \frac{BC}{(C - C_S)[1 + (B-1)(C/C_S)]} \Rightarrow \frac{C}{q(C_S - C)} = \frac{1}{BQ} + \frac{(B-1)\left({}^{C}/{}_{C_S}\right)}{BQ}$$

C_S = Saturation concentration in the liquid
B = a constant related to the energy of the interaction between the sorbent and sorbate

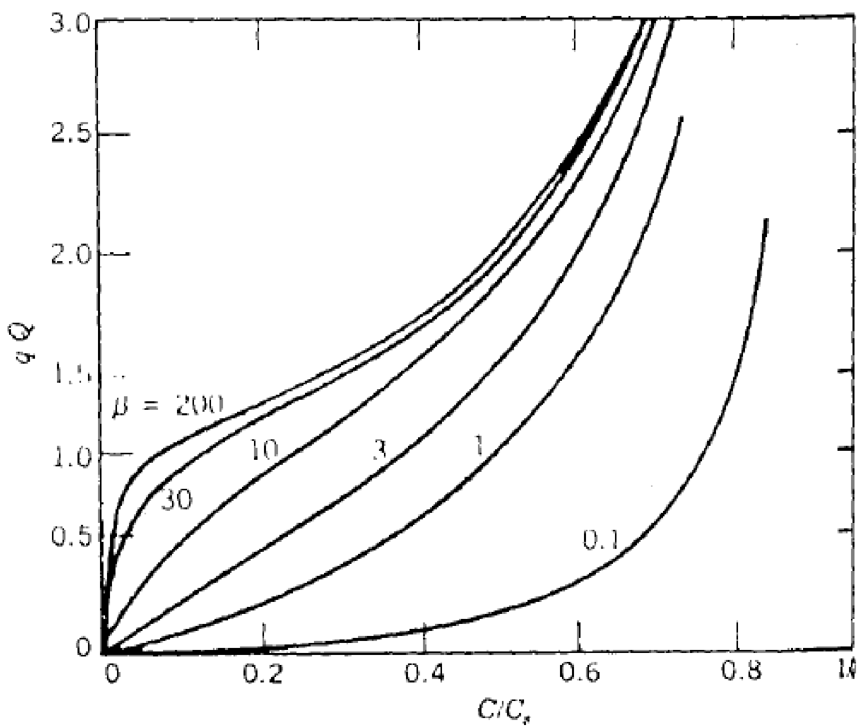


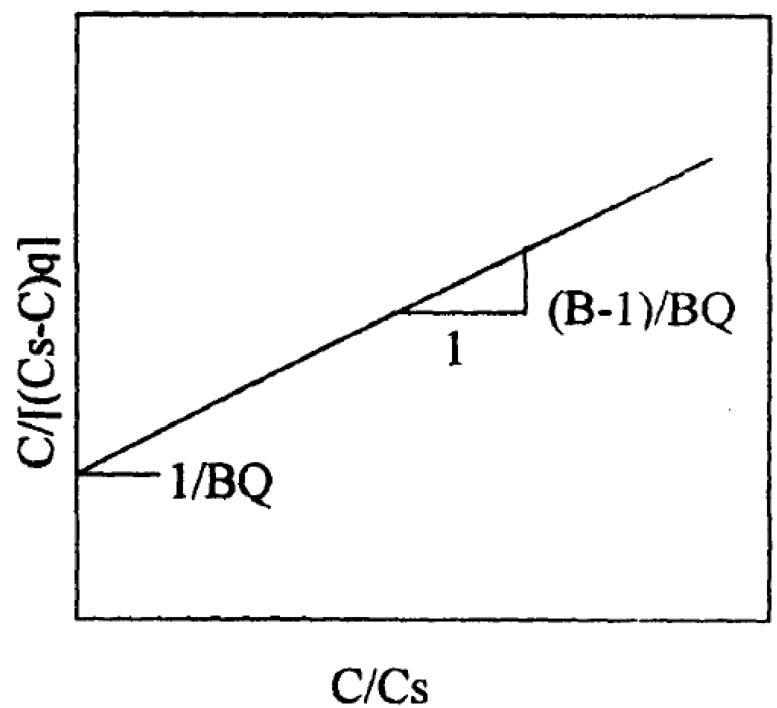


BET Isotherm (multi-layer adsorption)

$$\frac{q}{Q} = \frac{BC}{(C - C_S)[1 + (B-1)(C/C_S)]} \Rightarrow \frac{C}{q(C_S - C)} = \frac{1}{BQ} + \frac{(B-1)\left(C/C_S\right)}{BQ}$$

C_S = Saturation concentration in the liquid
B = a constant related to the energy of the interaction between the sorbent and sorbate

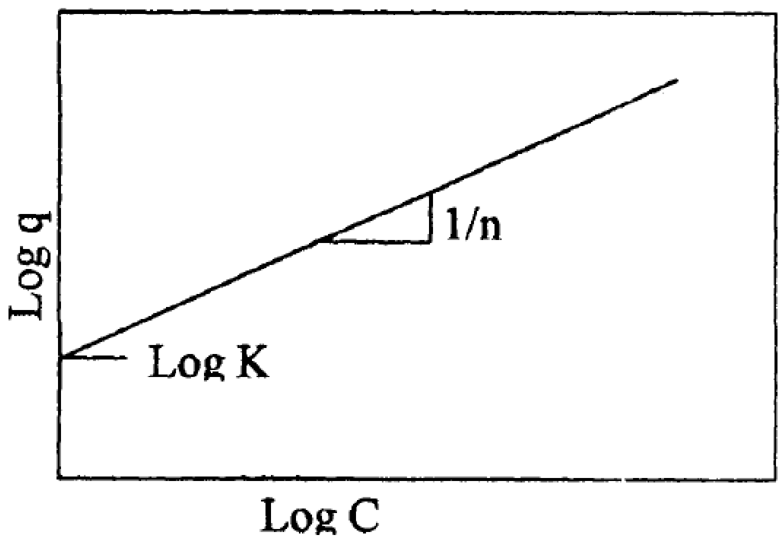




Freundlich isotherm

Assumption: frequency of sites associated with a free energy of adsorption decreases exponentially with increasing free energy.

$$q = kC^{1/n} \Rightarrow logq = logk + (1/n)logC$$



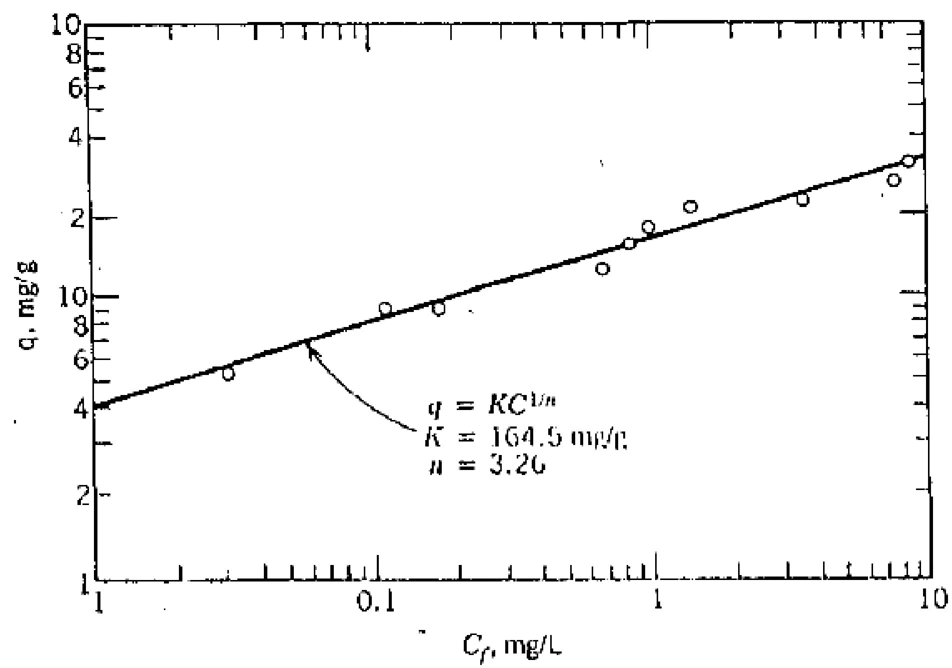


FIGURE 9-17. Freundlich isotherm for benzidine adsorption.

Problem

An engineer performed the following adsorption experiment of benzidine on granular carbon.

Carbon dose, M (mg/L)	Initial conc. Ci (mg/L)	Final conc., Cf (mg/L)
3.72	9.81	8.63
8.42	9.81	7.52
24.5	9.81	3.55
39.8	9.81	1.41
1.08	1.17	0.98
2.12	1.17	0.84
4.05	1.17	0.66
10.85	1.17	0.17
11.9	1.17	0.11
21.1	1.17	0.03

Plot the adsorption isotherm for this experiment. Estimate the parameters of the Langmuir isotherm. Using log-log paper, replot the data and estimate the parameters of the Freundlich isotherm.

Week-(12)

MD Ehasan Kabir

Coagulation

Stability of colloidal particles

Destabilization of colloidal particles

Factors affecting Coagulation

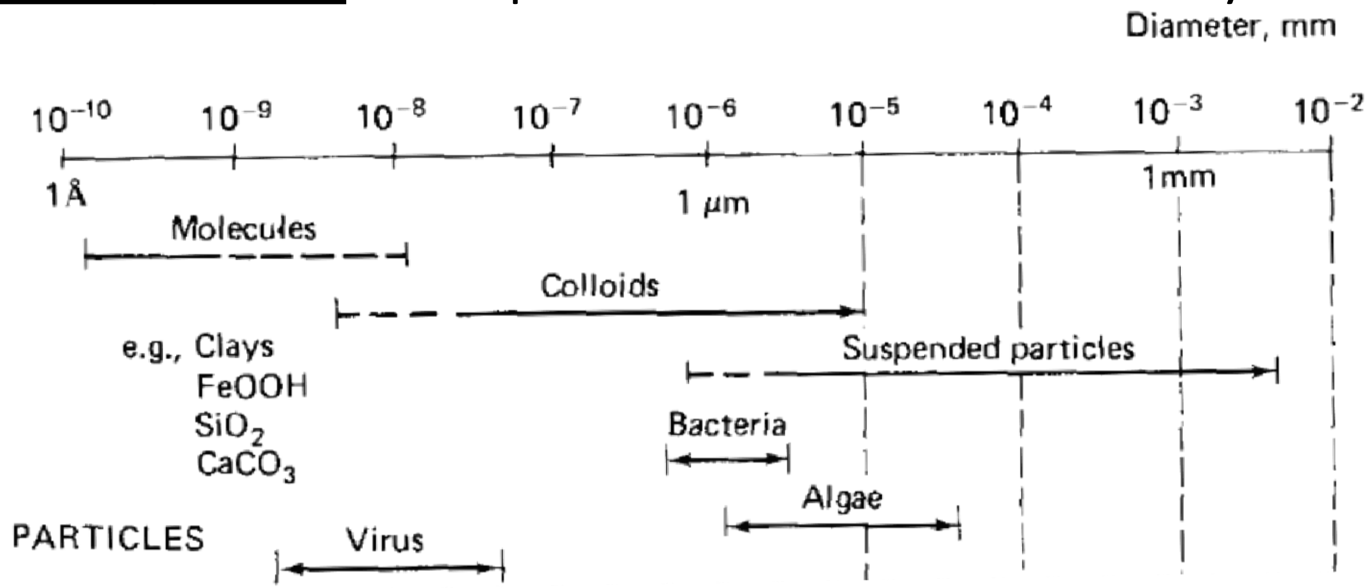
Coagulation of color

Mixing and Flocculation

Flocculator design considerations

What is coagulation?

Colloidal impurities are responsible for color and turbidity



Colloidal particles do not settle by gravity and pass through filters.

Colloidal particles can only be removed by promoting aggregation (and subsequent increase in size) by adding chemical agents.

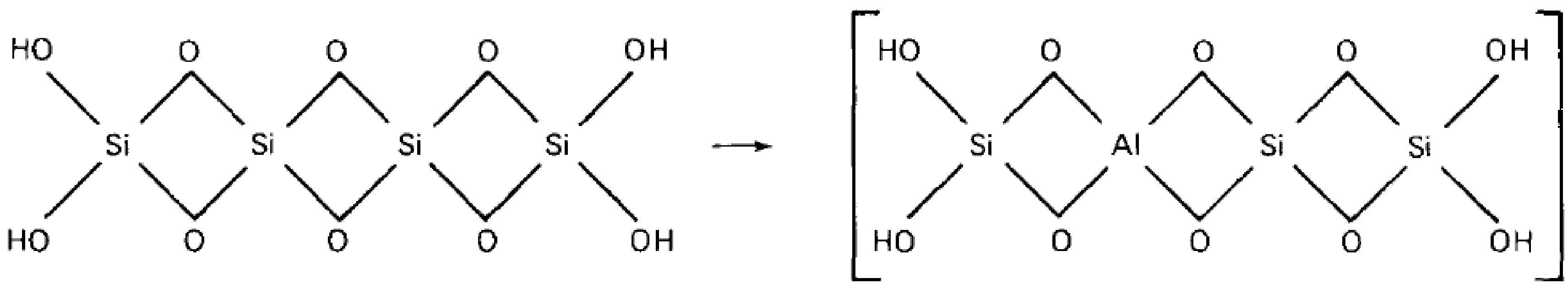
Coagulation

Stability of colloidal particles

Mechanism: electrostatic repulsion between charged particles

Electrical charge can be acquired in several ways:

1. **Imperfections in the crystal structure:** Isomorphous sustitution (ex: clay materials causing turbidity)



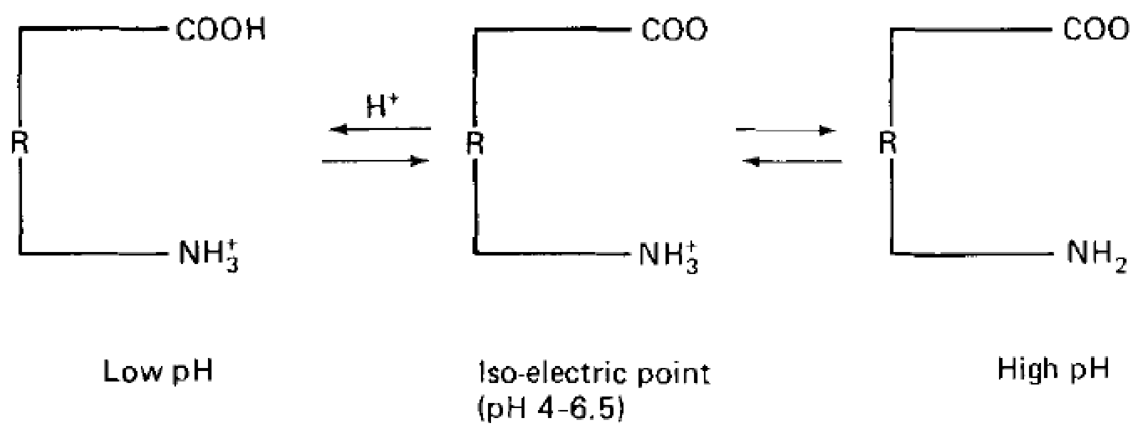
(a) Charge acquisition through isomorphic replacement of Al for Si. (after Fair, Geyer, and Okun, 1968.)

2. **Adsorption of ions onto particle surface:** Colloidal particles in aqueous media usually adsorb anions (ex: Gas bubbles oil droplets)

Stability of colloidal particles

3. **Ion dissolution:** Unequal dissolution of oppositely charged ions of which the colloids are composed

4. **Ionization of surface functional groups:** (ex: proteins by ionization of carboxyl or amino groups)
Ionization is pH dependent

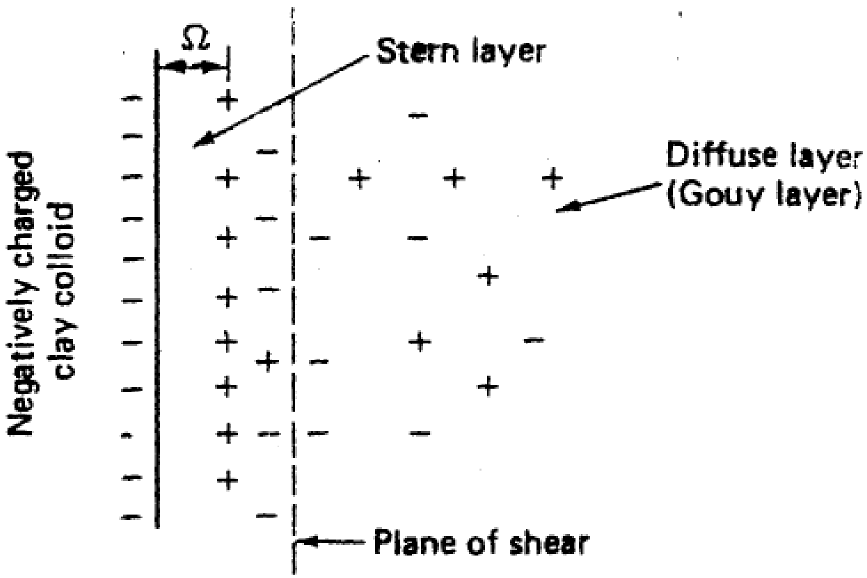


(b) Effect of pH on the ionization of a protein particle.

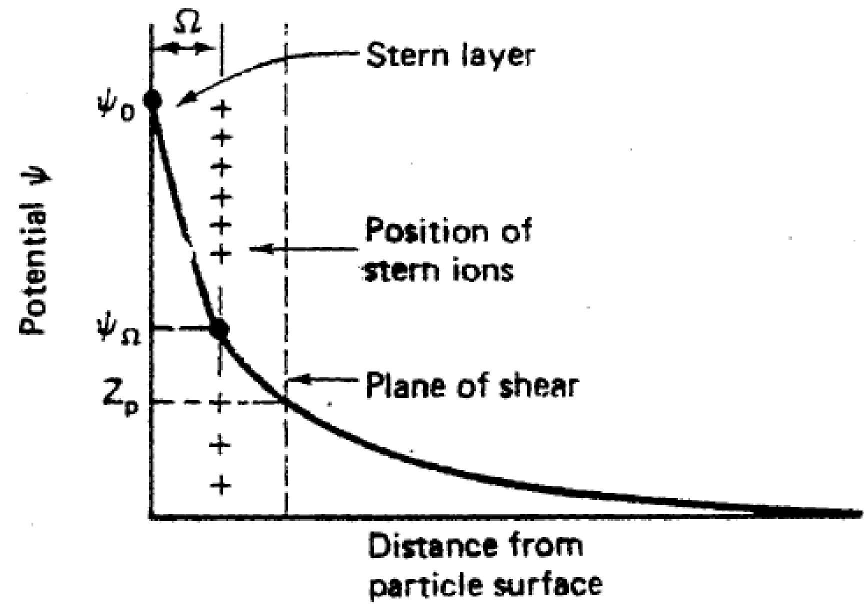
Hydrophobic colloids: electrical repulsion forces (clay particles)

Hydrophilic colloids: particle solvation (color-producing particles)

Stern's model of electrical double layer



(a) Distribution of charges in the vicinity of a colloidal particle



(b) Distribution of potential in the electrical double-layer

Z_p = zeta potential

q = charge on the particle

δ = thickness of the zone of influence of the charge on the particle

D = dielectric constant of the liquid.

Destabilization of colloidal particles

1. Reduction of surface potential by double layer compression
2. By adsorption and charge neutralization
3. Destabilization of colloids by enmeshment in a precipitate
4. Destabilization by Adsorption and charge neutralization

1. <u>Double-layer compression:</u>

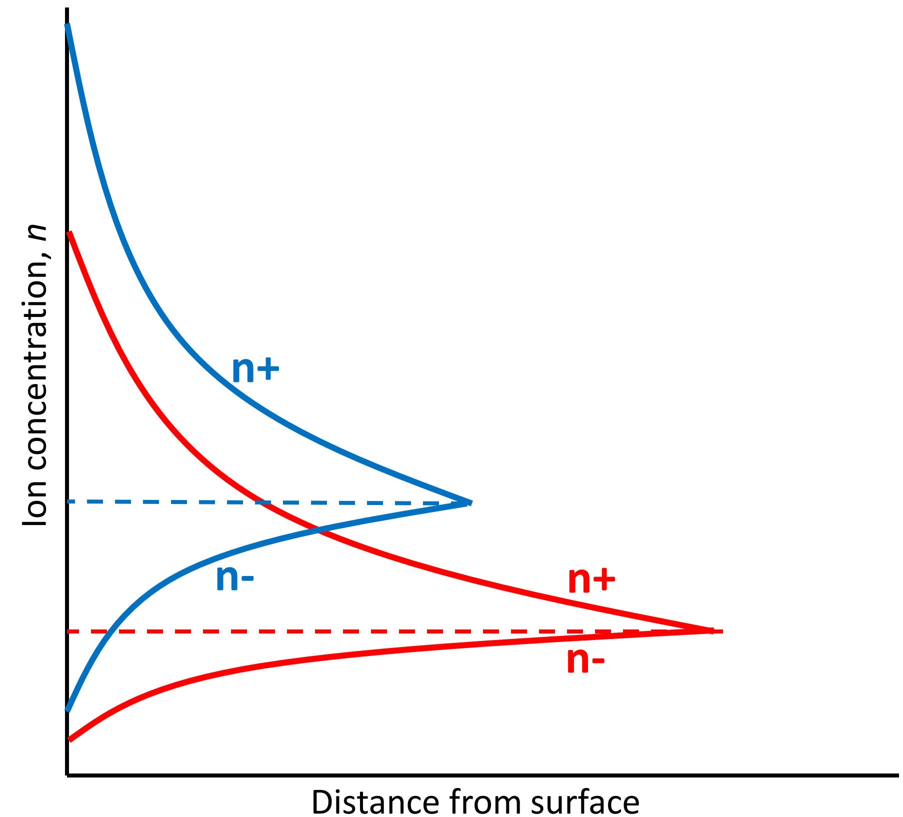
Electrolytes added

↓

Increased charge density in diffuse layer

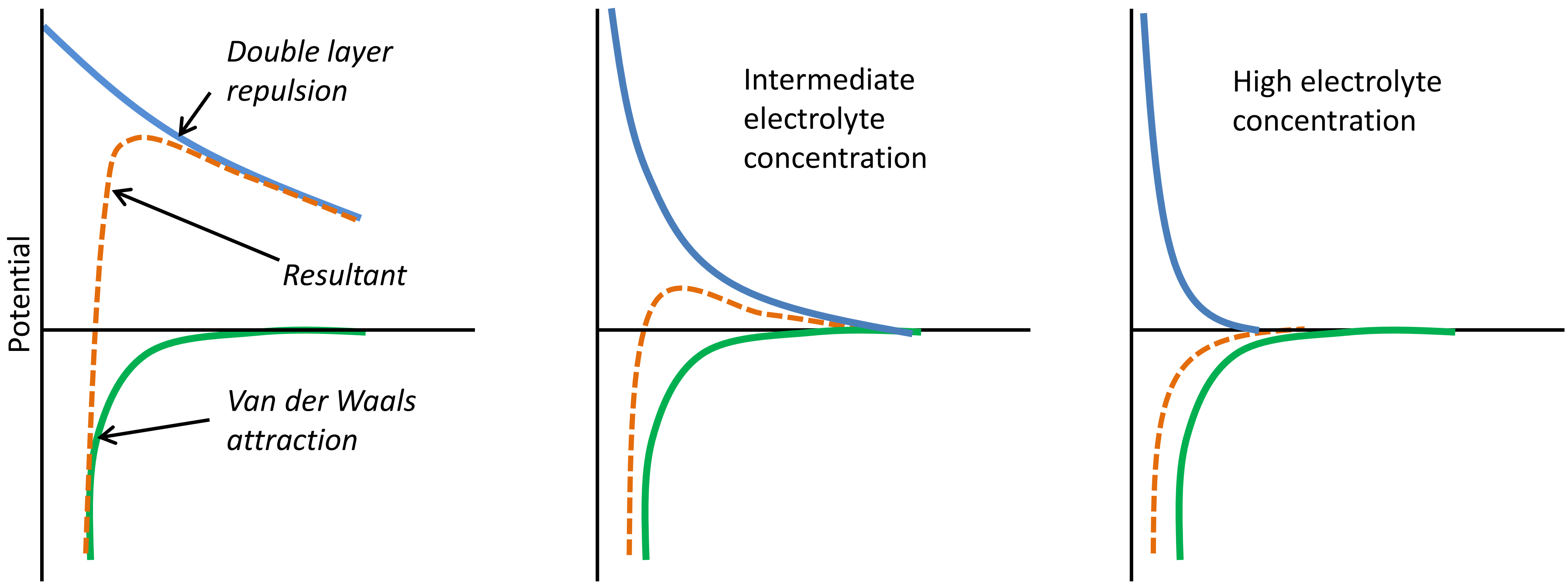
↓

Less volume of charge required to neutralize surface charge



Destabilization of colloidal particles

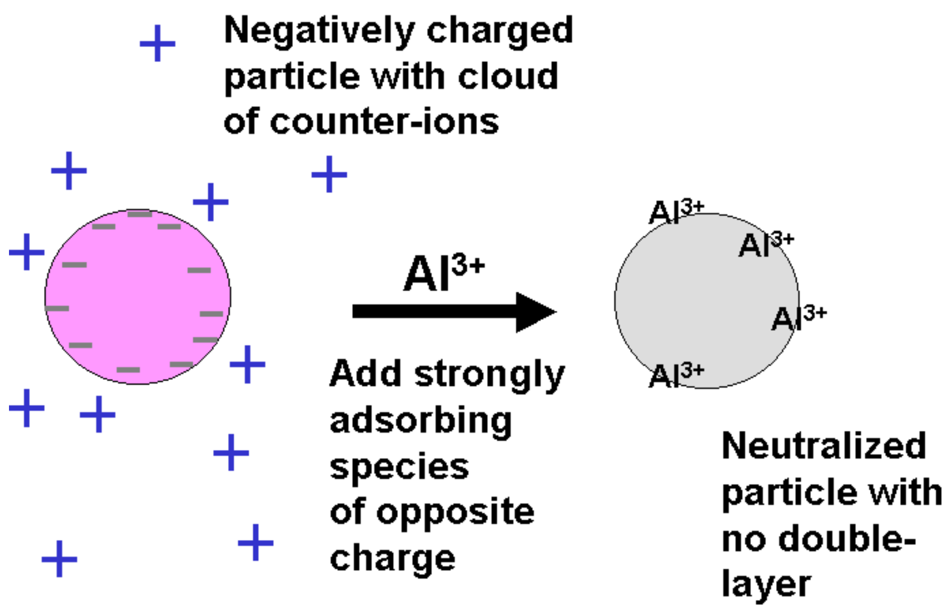
1. Double-layer compression:



Coagulation concentration for counter-ions with charge numbers 1, 2 and should be in the ratio of $1/1^6:1/2^6:1/3^6$ or 1000:16:1.3

Destabilization of colloidal particles

2. Adsorption and charge neutralization:



Difference with double-layer compression:

(a) Stoichiometric relationship with the concentration of colloids

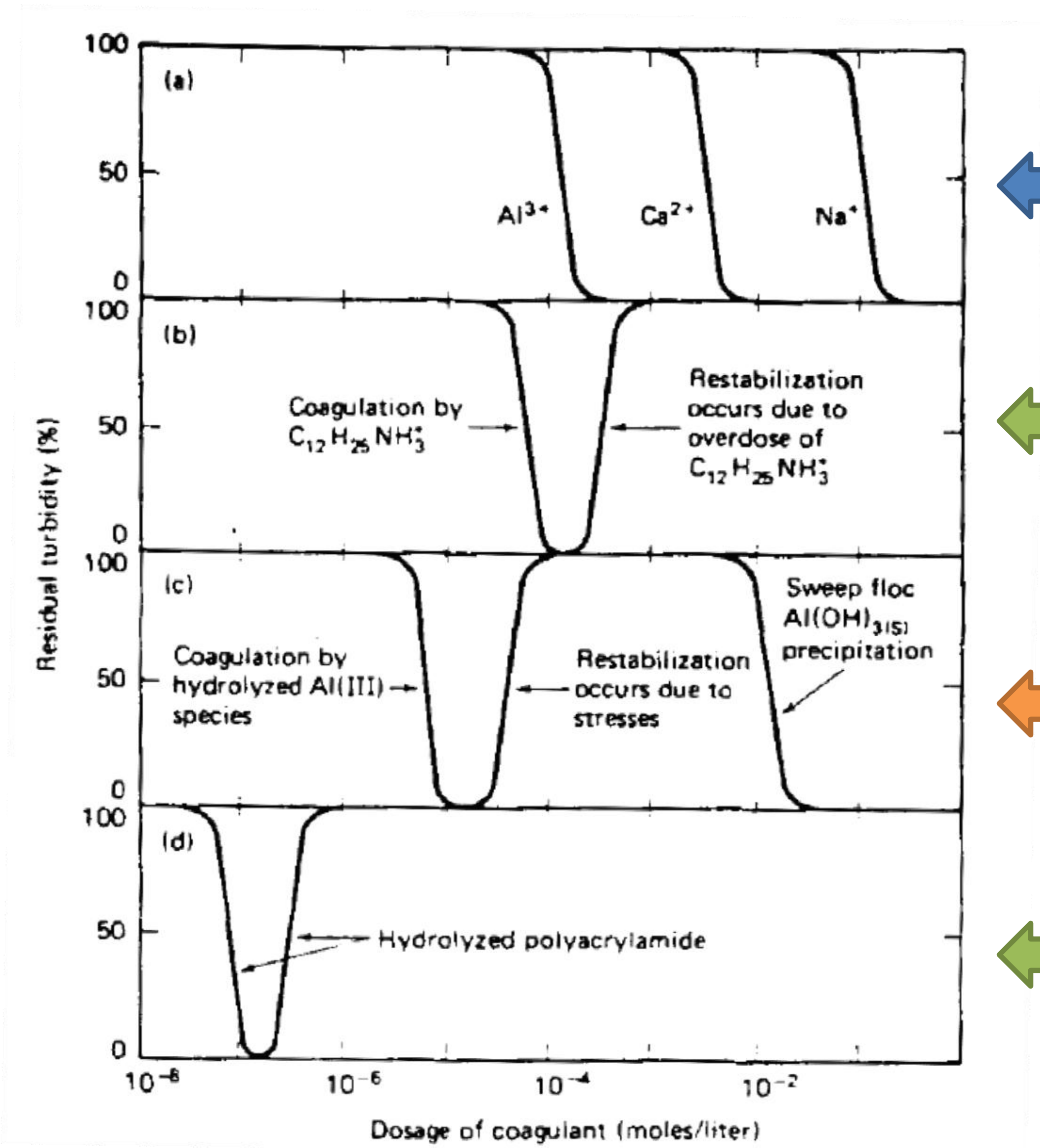
(b) Charge reversal possible with overdose

(c) Sorbable species capable of destabilizing colloids at lower dosages

3. Enmeshment in a precipitate:

Sufficient amount of coagulants ($Al_2(SO_4)$, $FeCl_3$, $MgCO_3$ and $Ca(OH)_2$) can generate rapid precipitates ($Al(OH)_3$, $Fe(OH)_3$, $Mg(OH)_2$ and $CaCO_3$) and colloids may become enmeshed in these. (Also called *Sweep floc* coagulation)

Destabilization of colloidal particles



Double-layer compression

Adsorption

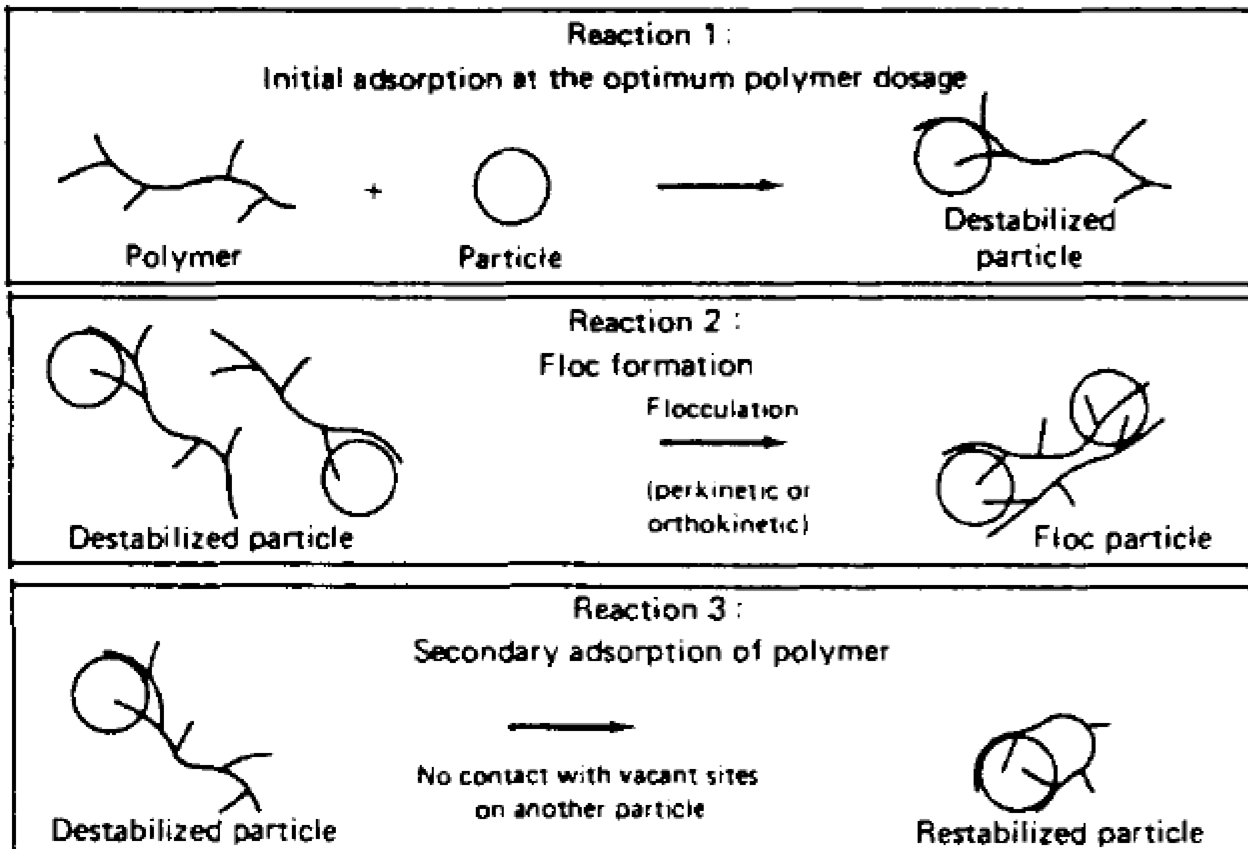
Adsorption and sweep floc

Adsorption with polymers

Destabilization of colloidal particles

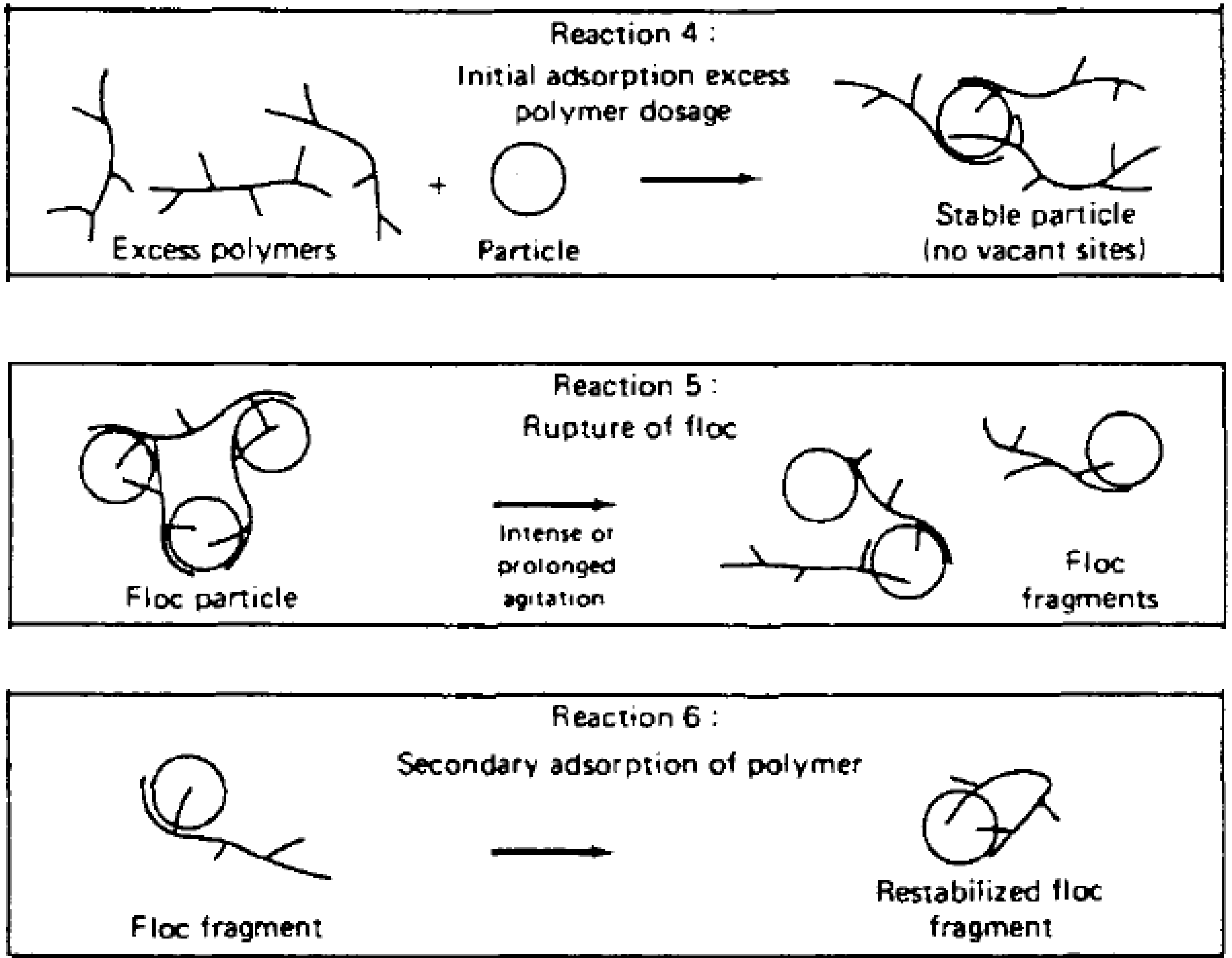
4. Adsorption and interparticle bridging:

Some molecules having large molecular size are useful coagulating agents (starch, cellulose, polysaccharide gums, proteineous materials, synthetic polymeric compounds)

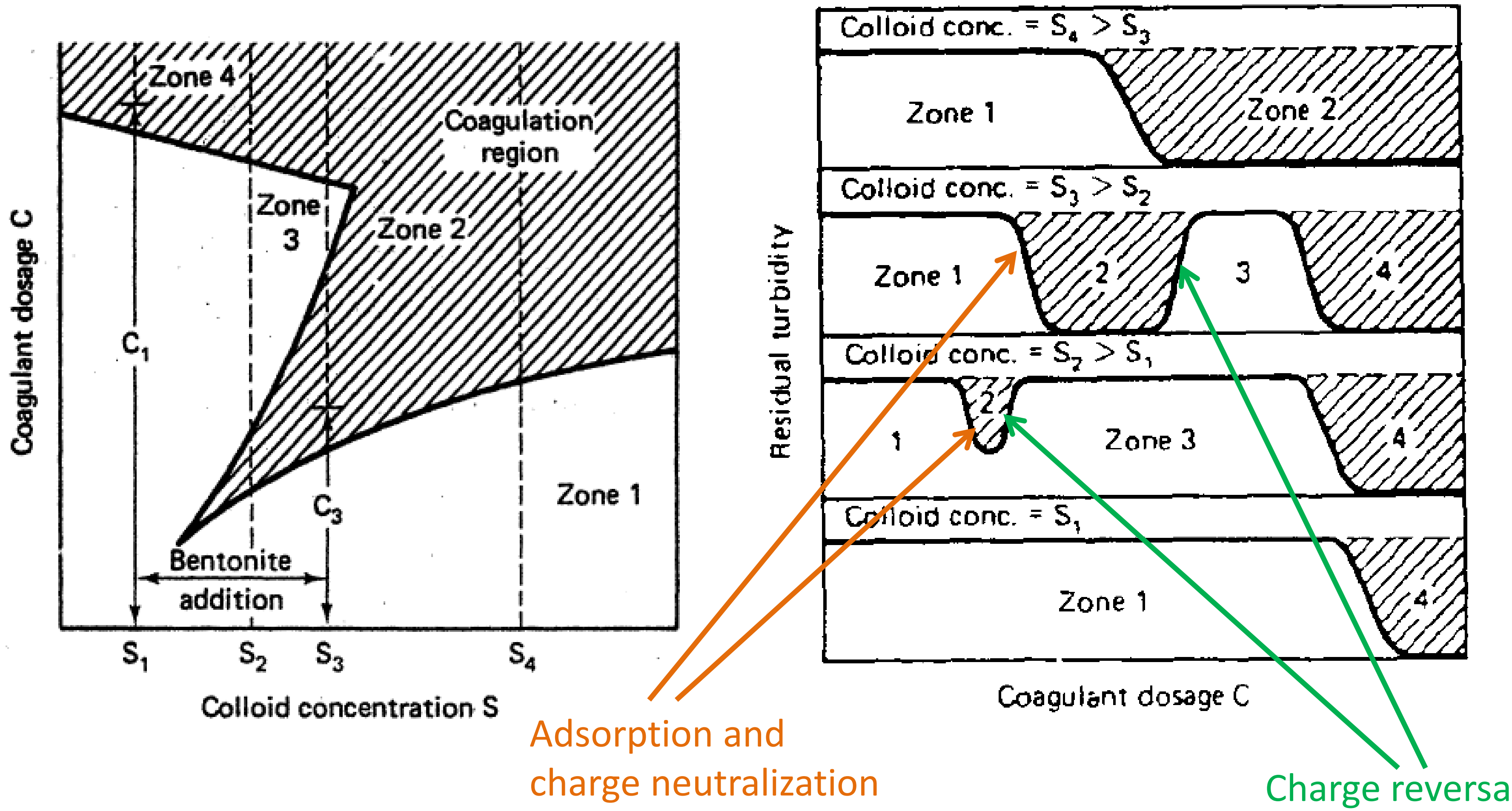


Destabilization of colloidal particles

4. Adsorption and interparticle bridging:

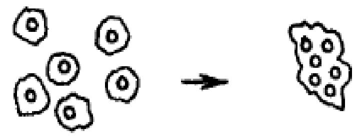
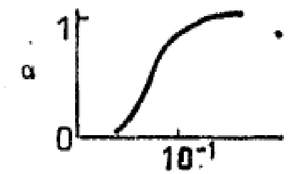
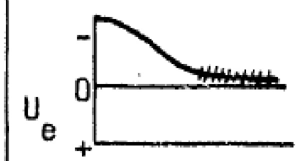
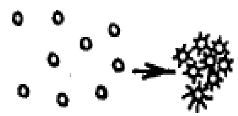
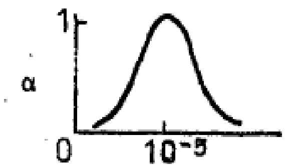
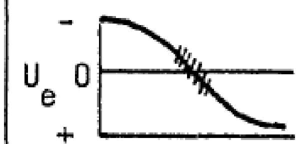
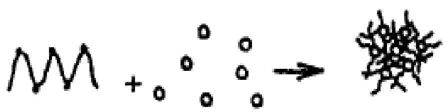
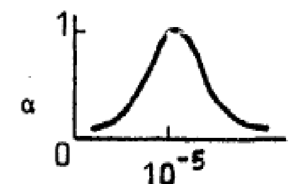
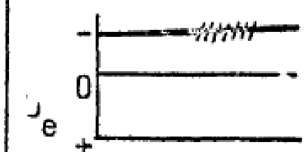
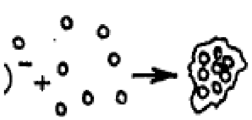
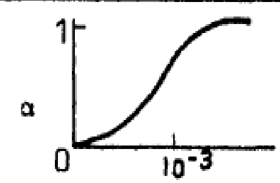
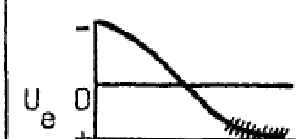


Coagulant dosage and colloid concentration



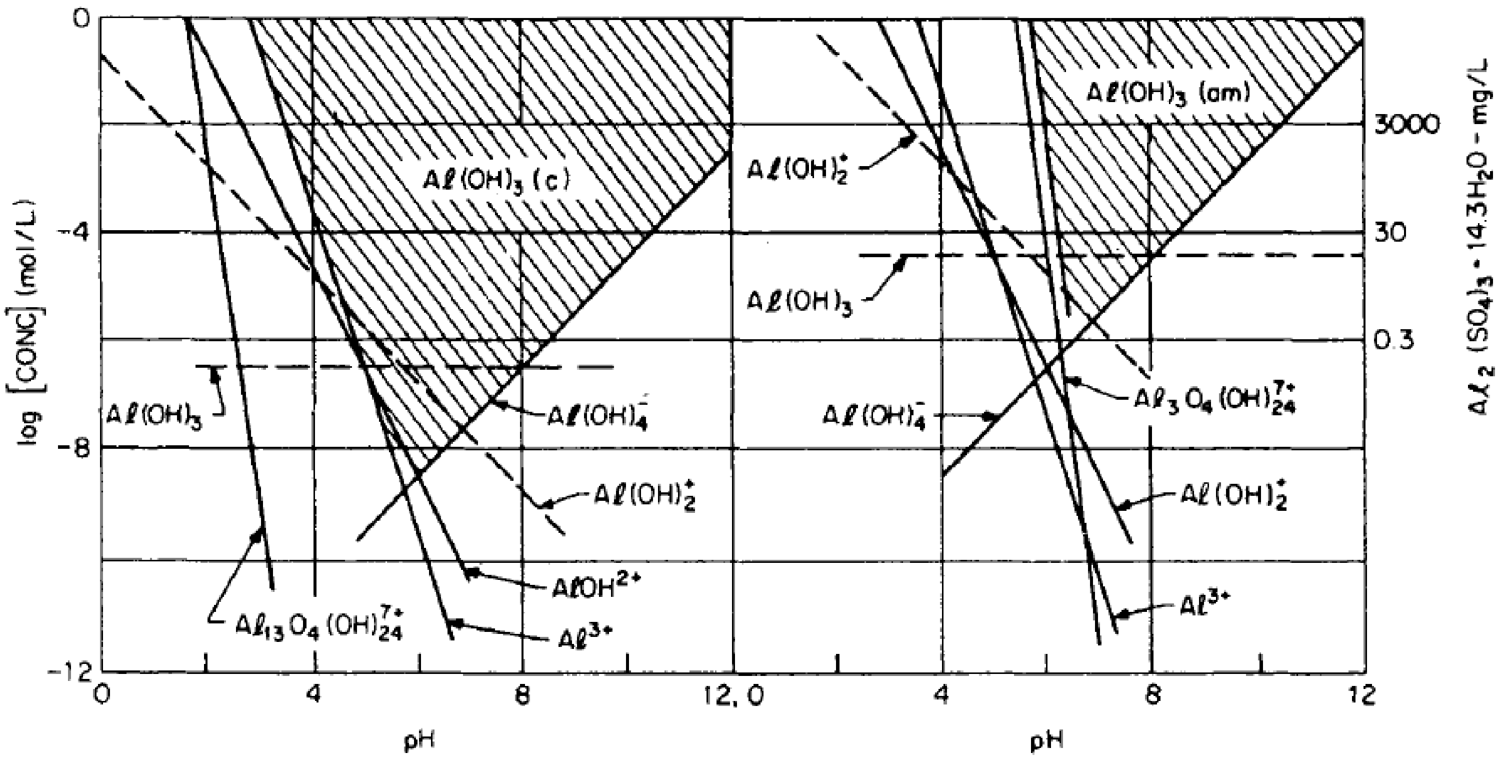
- ❑ Inverse relationship between C and S for sweep floc coagulation
- ❑ Stoichiometric relationship associated with adsorption and charge neutralization

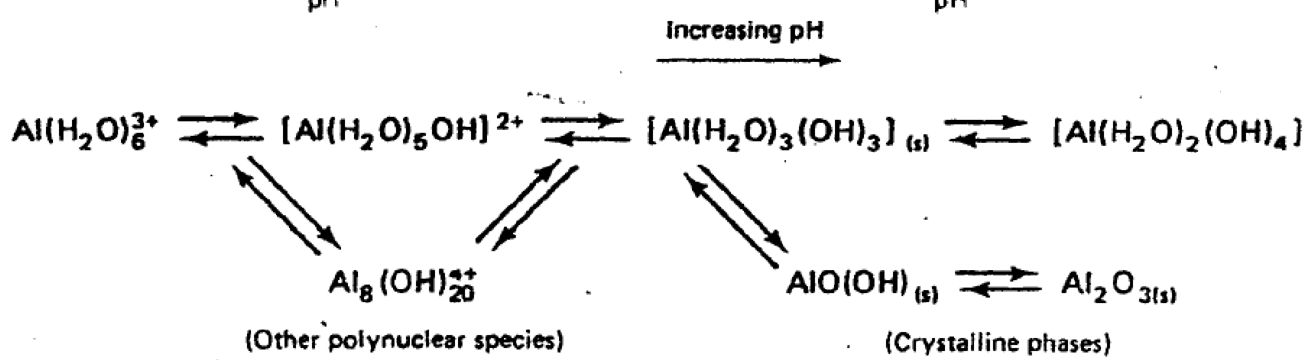
Schematic summary of colloidal destabilization

Type of Destabilization	Conceptual picture of the action	Degree of destabilization α and dose	Electrophoretic mobility (U_e) and dose	Reqd. dose for α optimum and colloidal surface conc.
Double-layer compression	nNa^+ + 	 α; 1; 0; 10^{-1}; Dose (mol/l)	 U_e; −; 0; +; Dose	Independent
Adsorption and charge neutralization	$nAl^{+++} + m(OH)^- +$ 	 α; 1; 0; 10^{-5}; Dose (mol/l)	 U_e; −; 0; +; Dose	Direct Proportionality
Adsorption and inter-particle bridging	n 	 α; 1; 0; 10^{-5}; Dose (mol/l)	 U_e; −; 0; +; Dose	Direct Proportionality
Enmeshment in precipitate (sweep flocu-lation)	$nAl^{+++} + 3n(OH)^- +$  $Al(OH)_3$	 α; 1; 0; 10^{-3}; Dose (mol/l)	 U_e; −; 0; +; Dose	Inverse Relationship

* ///////// Region where α approaches optimum

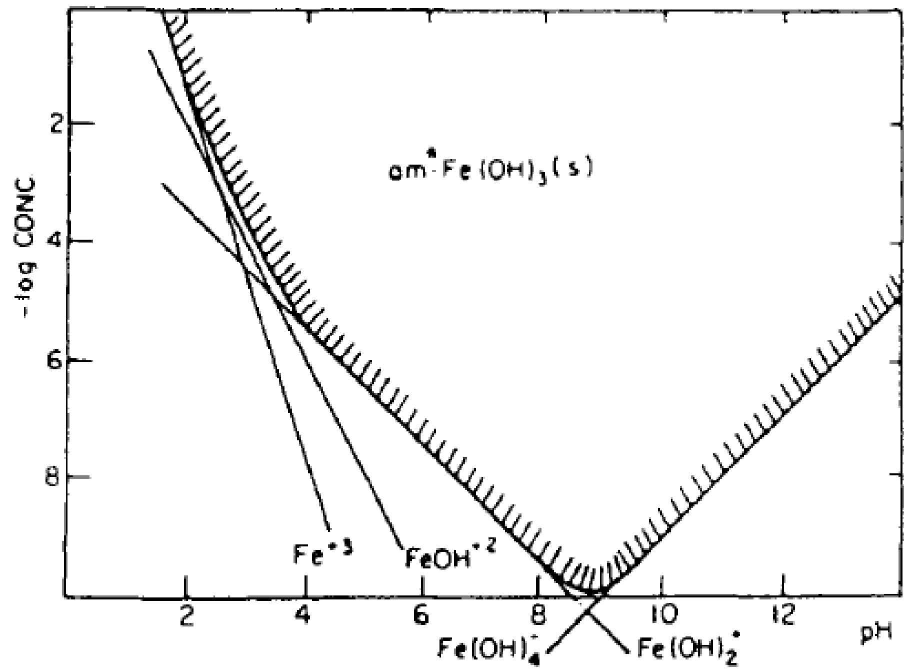
pH controls the solubility of Al-hydrocomplexes

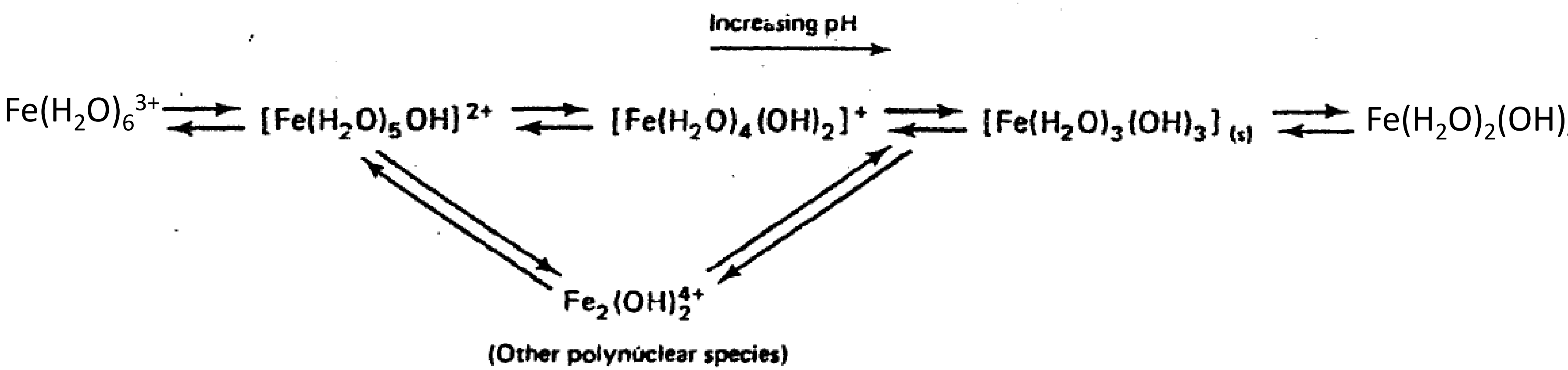




(b) Hydrolysis scheme for aluminum (III)

pH controls the solubility of Fe-hydrocomplexes





(a) Hydrolysis scheme for iron (III)

Alkanlinity requirement for coagulation

Aquometal ions are acidic in nature and liberate H^+

$$Al(H_2O)_6^{3+} + H_2O \rightleftharpoons Al(H_2O)_5(OH)^{2+} + H_3O^+$$

Natural alkalinity will react with the hydrogen ions liberated from the addition of alum

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4 + 14H_2O + 6CO_2$$

If natural alkilinity is not enough, it may be necessary to add alkalinity to buffer the pH

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(OH)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4 + 14H_2O$$

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Na_2CO_3 + 3H_2O \longrightarrow 2Al(OH)_3 + 3Na_2SO_4 + 3CO_2 + 14H_2O$$

Example problem

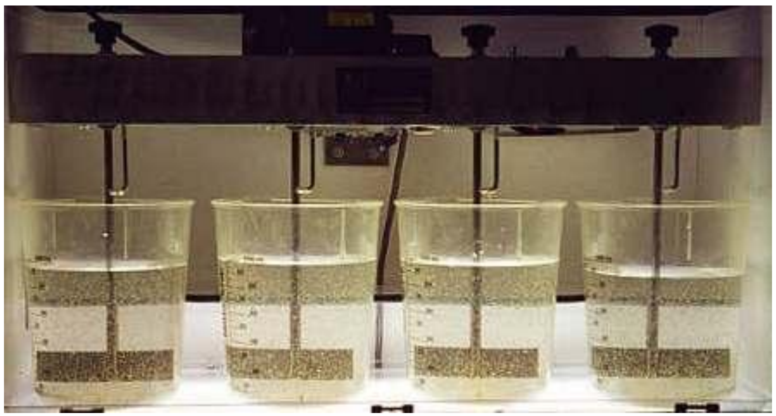
A raw water supply is treated with an alum dosage of 25 mg/L. Calculate the following:

1. The amount of alum required to treat a flow of 1 MGD
2. The amount of natural alkalinity required to react with the alum added
3. The folume of $Al(OH)_3$ sludge produced per MGD if it is collected at 2% solids. Assume that the dry solids have a specific gravity of 2.2.

<u>Reaction:</u>

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4 + 14H_2O + 6CO_2$$

Guidelines for selecting a coagulant



Jar test to calculate dosage

TABLE 7-2 Comparison of various coagulants (after Weber, 1972).

Type of Water	*Alum*	*Ferric Salts*	*Polymer*	*Magnesium*
High turbidity. High alkalinity. (easiest to coagulate). (Type 1)	Effective for pH 5–7. Addition of alkalinity and coagulant aid not required.	Effective for pH 6–7. Addition of alkalinity and coagulant aid usually not required.	Cationic polymers very effective. Anionic and non-ionic may also be effective. High molecular weight materials are best.	Effective due to precipitation of $Mg(OH)_2$.
High turbidity. Low alkalinity. (Type 2)	Effective for pH 5–7. May need to add alkalinity if pH drops during treatment.	Effective for pH May need to add alkalinity if pH drops during treatment.	Same as above.	Effective and results in increased alkalinity, which makes water easier to stabilize.
Low turbidity. High alkalinity (Type 3)	Effective in relatively large dosages, which promote precipitation of $Al(OH)_{3(s)}$. Coagulant aid may be needed to weight floc and improve settling.	Effective in relatively large dosages, which promote precipitation of $Fe(OH)_{3(s)}$. Coagulant aid should be added to weight floc and improve settling.	Cannot work alone due to low turbidity. Coagulant aids such as clay should be added ahead of polymer.	Effective due to precipitation of $Mg(OH)_2$.
Low turbidity. Low alkalinity (most difficult to coagulate). (Type 4)	Effective only by sweep-floc formation, but resulting dosage will destroy alkalinity. Must add alkalinity to produce type 3 or clay to produce type 2 water.	Effective only by sweep-floc formation, but resulting dosage will destroy alkalinity. Must add alkalinity to produce type 3 or clay to produce type 2 water.	Will not work alone due to low turbidity. Coagulant aids such as clay should be added ahead of polymer.	Results in increased aklalinity, which makes water easier to stabilize.

Low turbidity < 10 JTU, low alkalinity < 50 mg/ℓ (as $CaCO_3$).
High turbidity > 100 JTU, high alkalinity > 250 mg/ℓ (as $CaCO_3$).

Rapid mixing and Flocculation

Mixing units are required to distribute the coagulants evenly throughout the system.

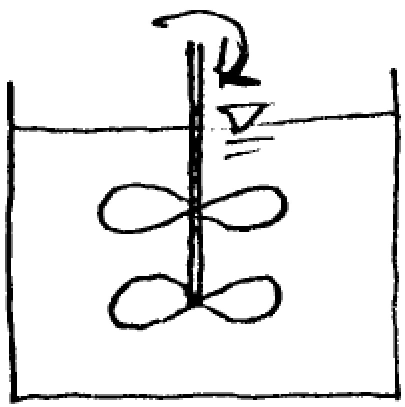
Mixing units should be selected based on the colloidal destabilization mechanism that needs to be achieved.

Mechanical Mixing

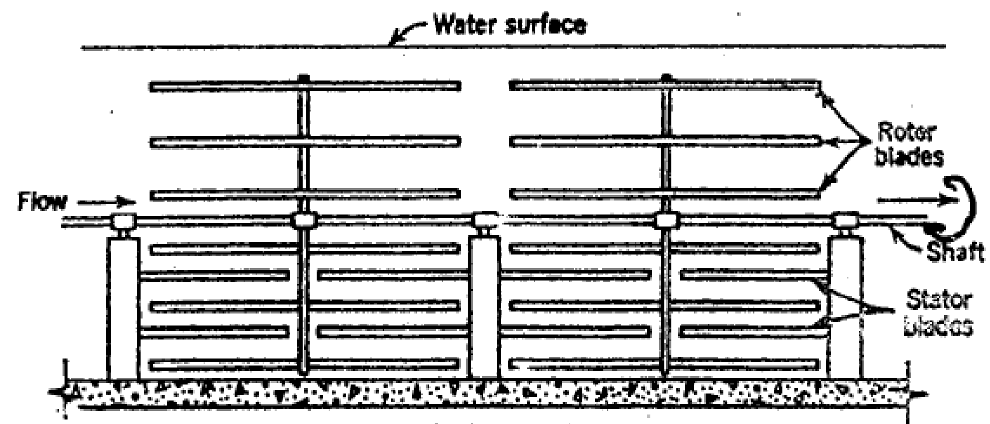
a. **Paddles**

b. **Turbine Impeller**

c. **Propeller**



Impeller / propeller.



Paddled Mixer

Rapid mixing and flocculation

Hydraulic Mixing

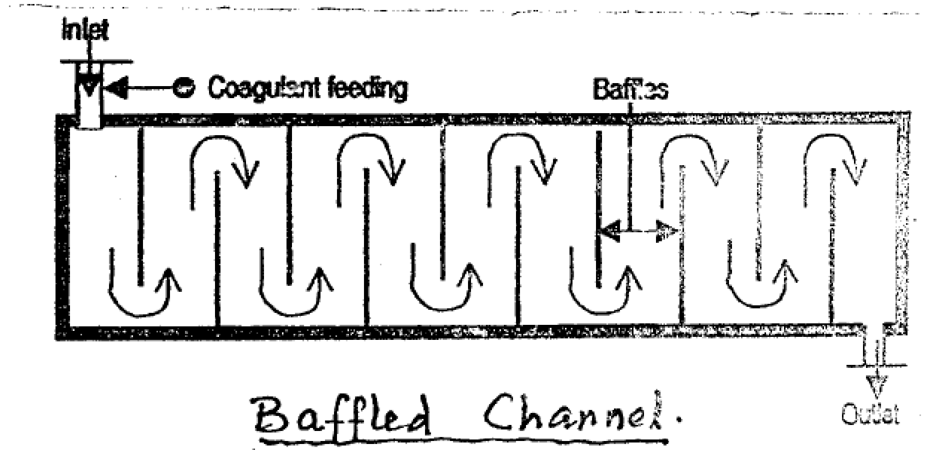
a. **Baffled Channel**

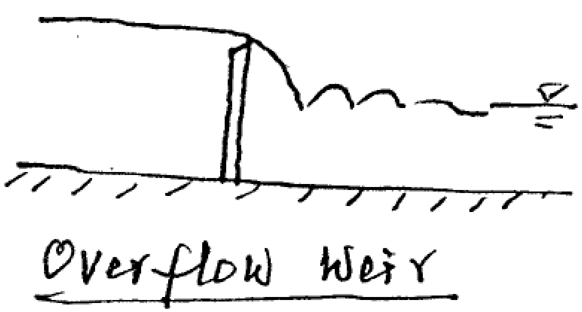
b. **Hydraulic Jump**

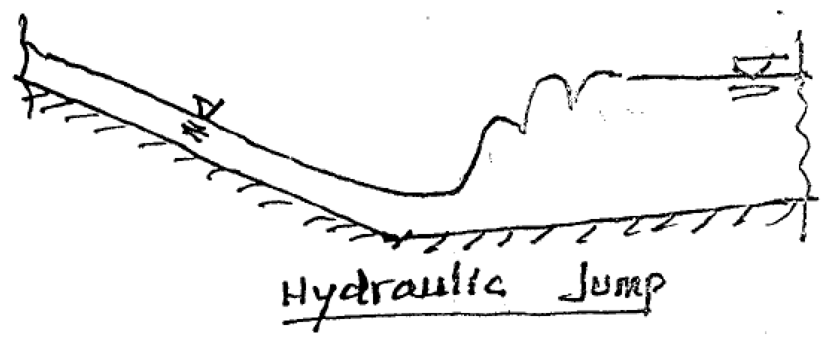
c. **Overflow Weirs**

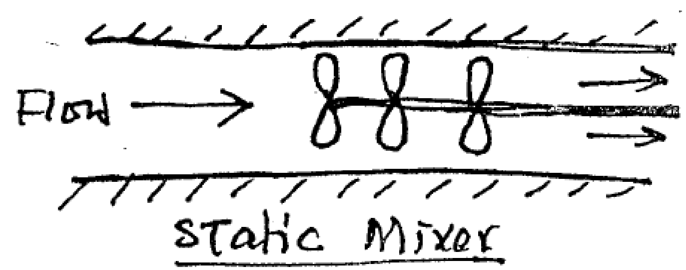
d. **Diffusers and Injection Devices**

e. **Static Mixers**









Measuring the degree of mixing

Velocity gradient: $$G = \sqrt{P/(\mu V)}$$

P = power input (W)
V = volume of basin(cu. m)
μ = fluid viscosity (Pa.s)

G values for rapid mixing

Detention time, t_0 (s)	G (s^{-1})
0.5	3500
10 – 20	1000
20 – 30	900
30 – 40	800
Longer	700

Gt_0 values for flocculation

Type	G (s^{-1})	Gt_0
Low turbidity, color removal coagulation	20 – 70	60,000 – 200,000
High turbidity, solids removal coagulation	50 - 150	90,000 – 180,000
Softening, 10% solids	130 - 200	200,000 – 250,000
Softening, 39% solids	150 - 300	390,000 – 400,000

Designing a flocculator

Power input:

$$P = \frac{K_T (n)^3 (D_i)^5 \rho}{g}$$

K_T = impeller constant
n = rotational speed (rpm)
Di = impeller dia (m)

Values of impeller constant K_T

Type of impeller	K_T
Propeller, pitch of 1, 3 blades	0.32
Propeller, pitch of 2, 3 blades	1.00
Turbine, 6 flat blades, vaned disc	6.30
Turbine, 6 curved blades	4.80
Fan turbine, 6 blades at 45°	1.65
Shrouded turbine, 6 curved blades	1.08
Shrouded turbine, with stator, no baffles	1.12

Power and rotational speed of some standard mixers

Model	n (rpm)	P (kW)
JTQ50	30, 45	0.37
JTQ75	45, 70	0.56
JTQ100	45, 110	0.75
JTQ150	45, 110	1.12
JTQ200	70, 110	1.50
JTQ300	110, 175	2.24
JTQ500	175	3.74

JWI, Inc. of Holland

Flocculator Design problem

The city of "X" is planning for the installation of a water treatment plant to remove iron. A low-turbidity iron coagulation plant has been proposed with the following design parameters:

$Q = 2\ m^3/s$
Rapid mix, $t_0 = 20$ s
Rapid mix, $G = 1000\ s^{-1}$
Floc, $t_0 = 60$ min
Floc, $G = 30\ s^{-1}$
Water temperature = 18°C

Design the rapid mix and flocculation basins and size of the mixing equipment. Use the available models from JWI Holland, Inc

Orthokinetic and Perikinetic Flocculation

Perikinetic: particle contact by Brownian motion

$$J_{pk} = \frac{dN^\circ}{dt} = \frac{-4\eta kT}{3\mu}\left(N^\circ\right)^2$$

Orthokinetic: particle contact by stirring

$$J_{pk} = \frac{dN^\circ}{dt} = \frac{-2\eta G d^3}{3}\left(N^\circ\right)^2$$

N^0 = total particle concentration at time t
η = collision correction factor
k = Boltzmann's constant (1.38×10^{-16} erg/degree)
T = absolute temp (°K)
μ = fluid viscosity (gram/cm-sec)
d = particle diameter (cm)
G = velocity gradient

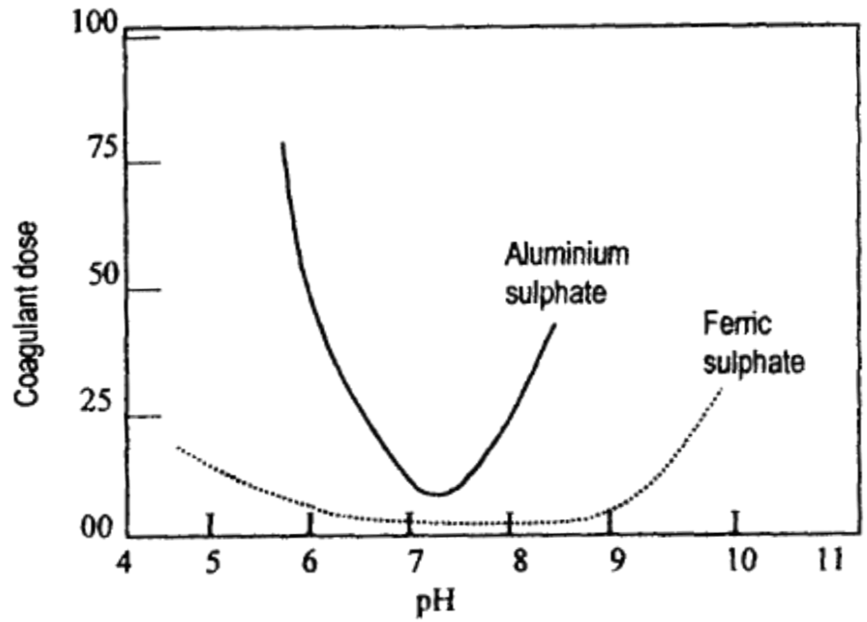
Perikinetic flocculation dominates when $\frac{J_{ok}}{J_{pk}} = \frac{\mu G d^3}{2kT} < 1$

Design velocity gradients 25/sec and 100/sec for Fe(III) and Al(III) respectively

Factors affecting coagulation

1. Effect of pH:

There is an optimum pH range for each salt where maximum coagulation-flocculation occurs in the shortest possible time with a given dosage of coagulant



2. Effect of coagulant:

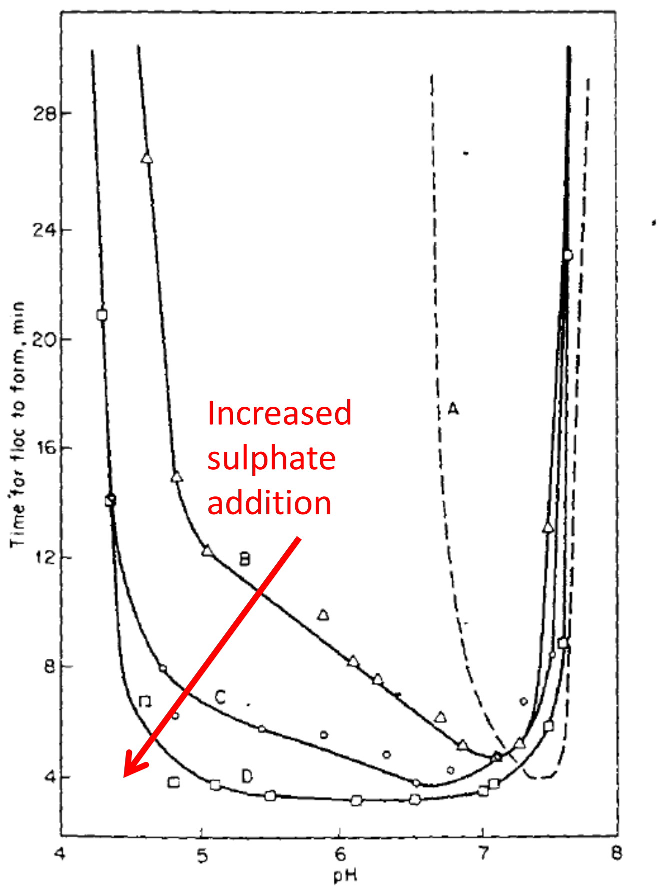
Iron salts usually have a broader optimum pH range (5.5 – 8.8 for Ferric Sulphate) than Aluminum salts (6.8 – 7.5 for Alum)

Iron salts are suitable for treatment in acid pH waters (i.e. soft colored waters) or highly alkaline waters.

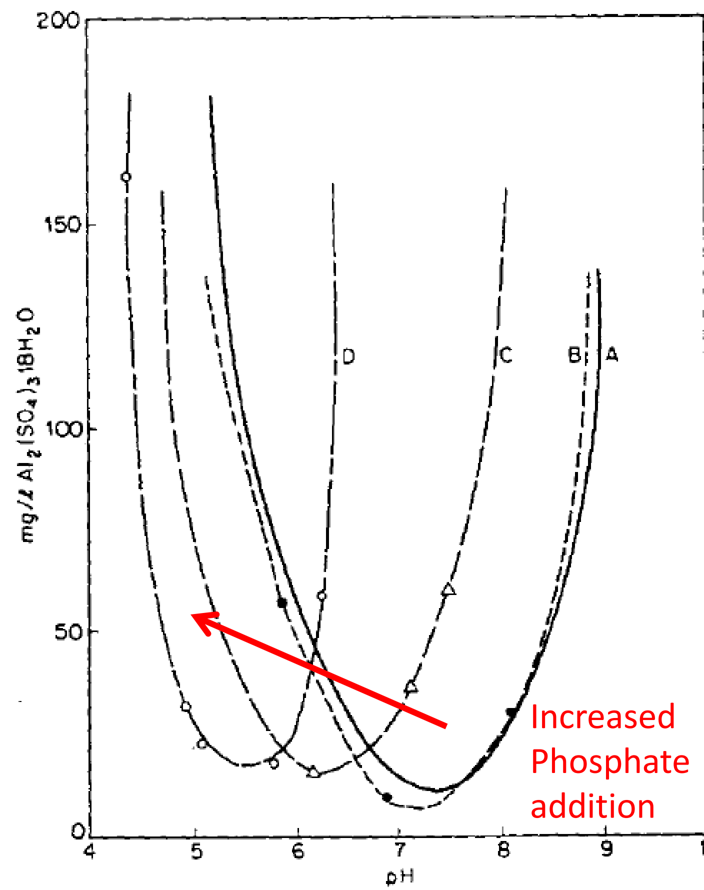
Factors affecting coagulation

3. **Effect of Salts:**

Presence of salts alter (a) pH range of optimum coagulation (b) time for flocculation (c) optimum coagulant dose (d) residual coagulant in effluent



Broadening of optimum pH range

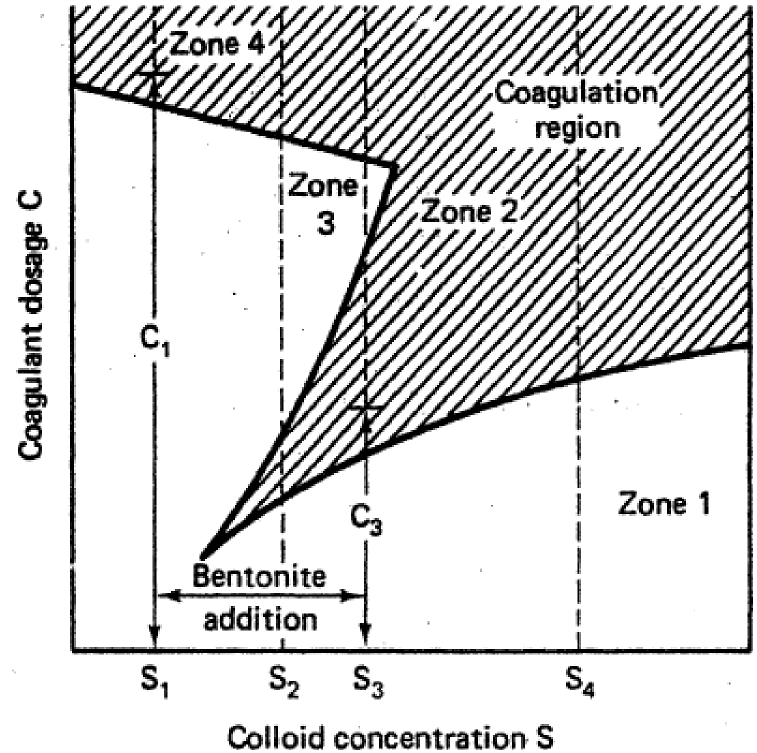


Shift in optimum pH with no broadening

Factors affecting coagulation

4. Effect of nature of turbidity:

- Low turbidity water is difficult to coagulate.
- With very high turbidity relatively smaller coagulant doses are required
- A broad distribution of clay particles are easy to coagulate than a suspension containing a narrow range of particle sizes.



5. Effect of physical factors:

Temperature decrease

- increases the viscosity of water which affects settling.
- Decreases the optimum pH value which will affect the coagulant dosage.

6. Presence of nuclei: affects the rate of floc formation

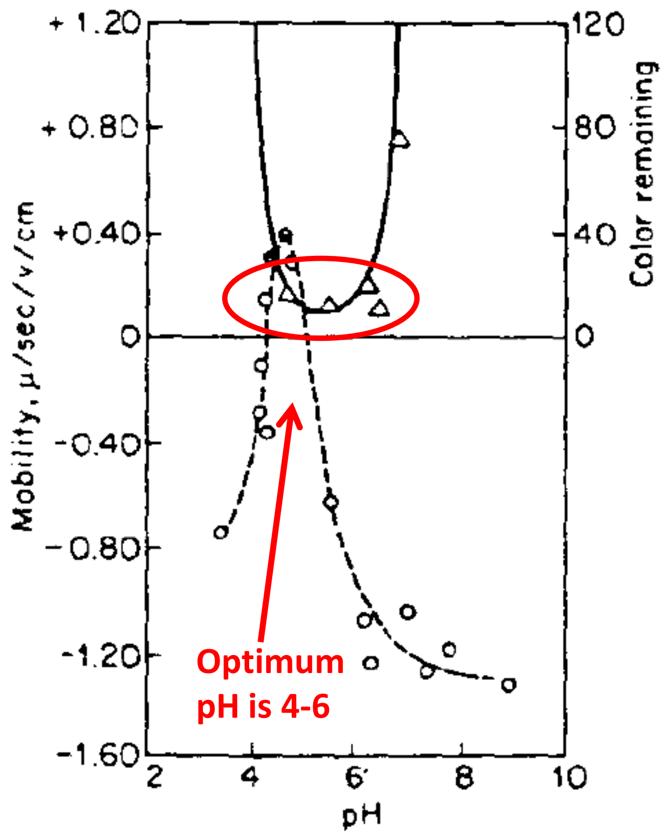
7. Effect of mixing: (a) Rapid/Flush mixing and (b) Gentle stirring

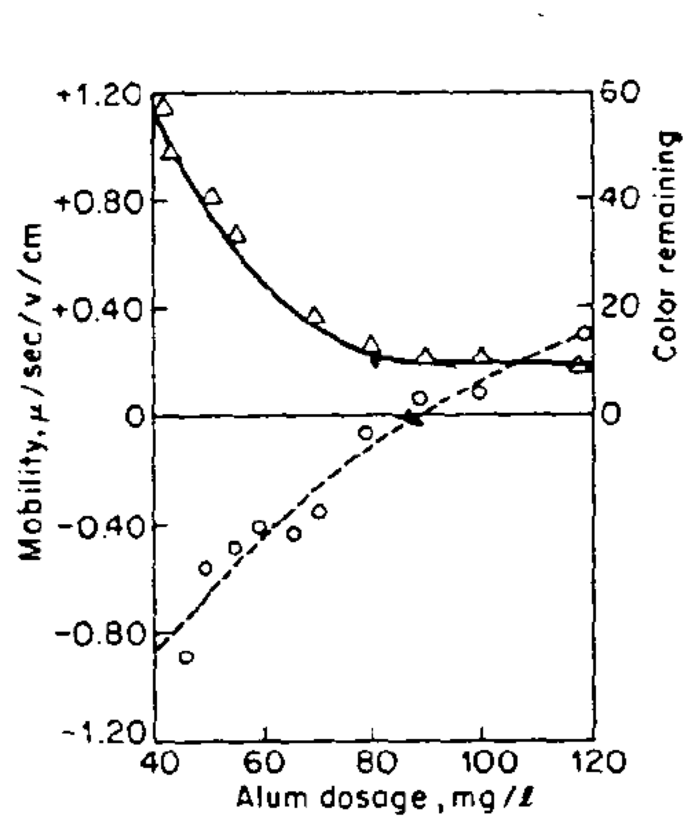
Coagulation of color

Causes of color: complex organic compounds having surface groups originating from decomposition of natural organic matter

Mechanism of removal :

hydrolized Fe/Al coagulant + acidic group on color molecules = insoluble basic salt





pH needs to be elevated after color removal prior to filtration

Week-(13)

MD Ehasan Kabir

Filtration

Mechanisms for particle removal

Transport process, attachment, detachment

Effect of process variables on collection efficiency

Mathematical analysis of flow through porous media

Roughing filters, SSF and RSF

Process selection

Why filtration?

- Sedimentation with or without coagulation will not ordinarily give clear sparkling and bacteriologically safe water
- Filter media are very efficient in retaining fine and colloidal particles of clay and silt.
- Aids in removing color, odor, iron and manganese
- Filters are capable of removing a wide range of particulate materials of both natural and human origin (algae, colloidal humic substances, viruses, asbestos fibers, colloidal clay particles) provided that proper design parameters are used.

Types of filters

- Granular materials (sand, anthracite, coal, magnetite) 0.1 – 10 mm

    Slow Sand Filter (SSF)

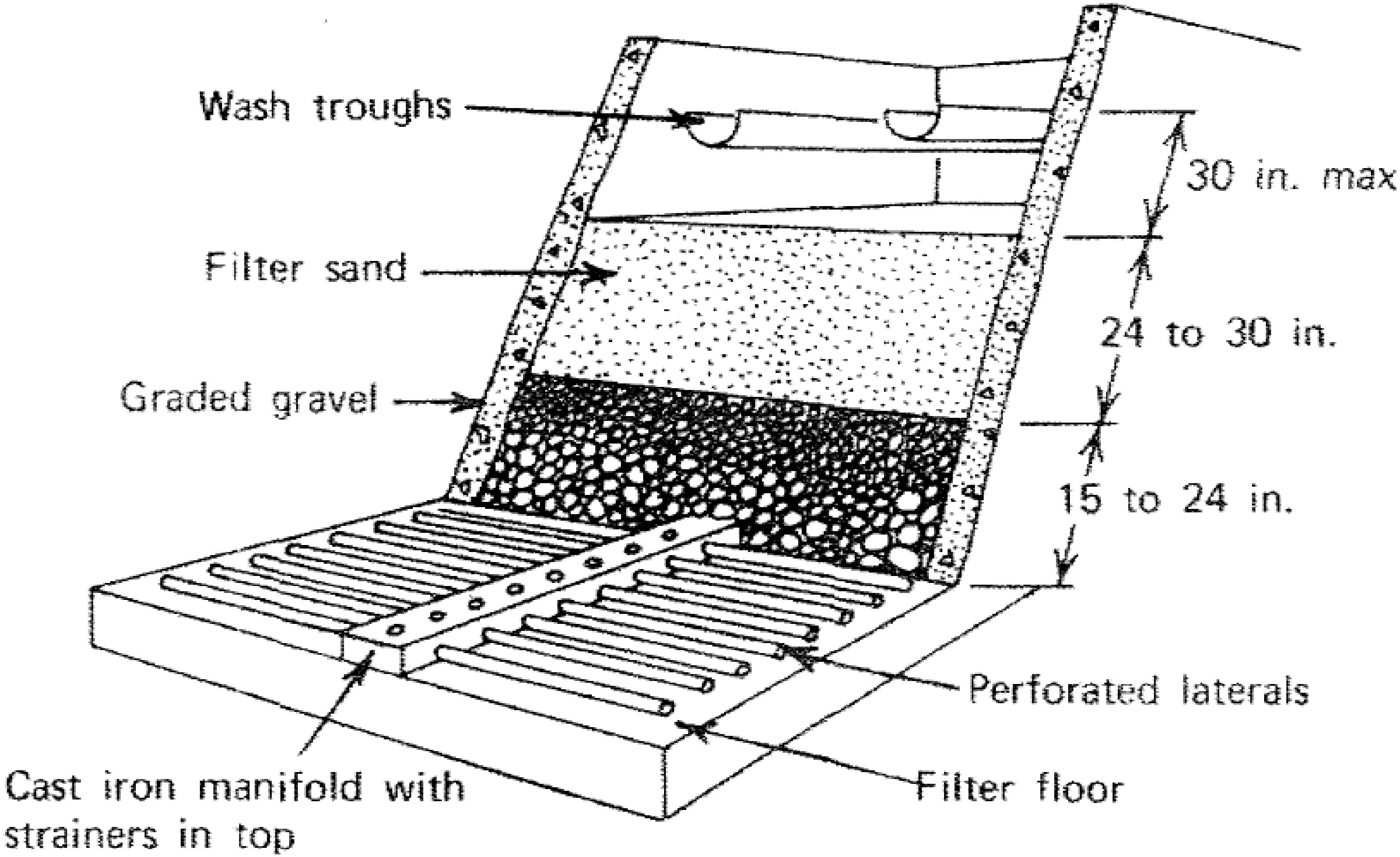
    Rapid Sand Filter (RSF)

    Roughing filters (RF)

- Diatomaceous earth(7 – 50 μm), a deposit formed form siliceous fossil remains of diatoms

- Membrane Filtration (0.45 – 0.2 μm), capable of removing bacteria and in some cases molecular separation

Underdrainage system and filter arrangement

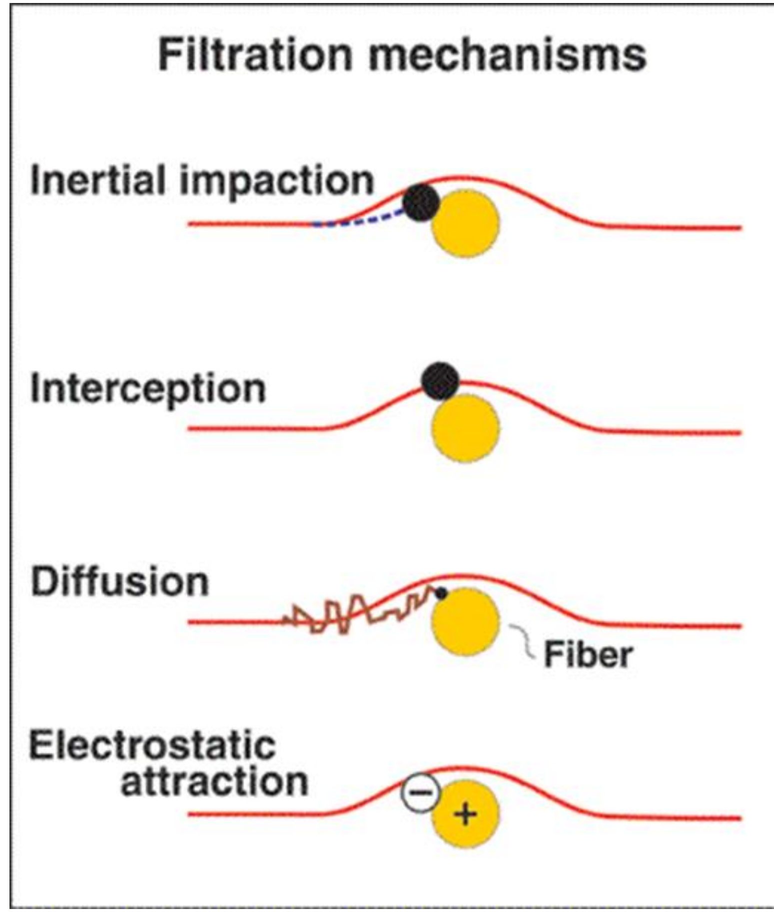


Mechanism for particle removal

In filtraiton process, particulate materials either accumulate on the surface or collected through the filter bed

(A) Physicochemical process

- Mechanical straining
- Non-straining mechanism
  - (Impaction, Interception, diffusion, electrostatic attraction etc.)



(B) Biological process

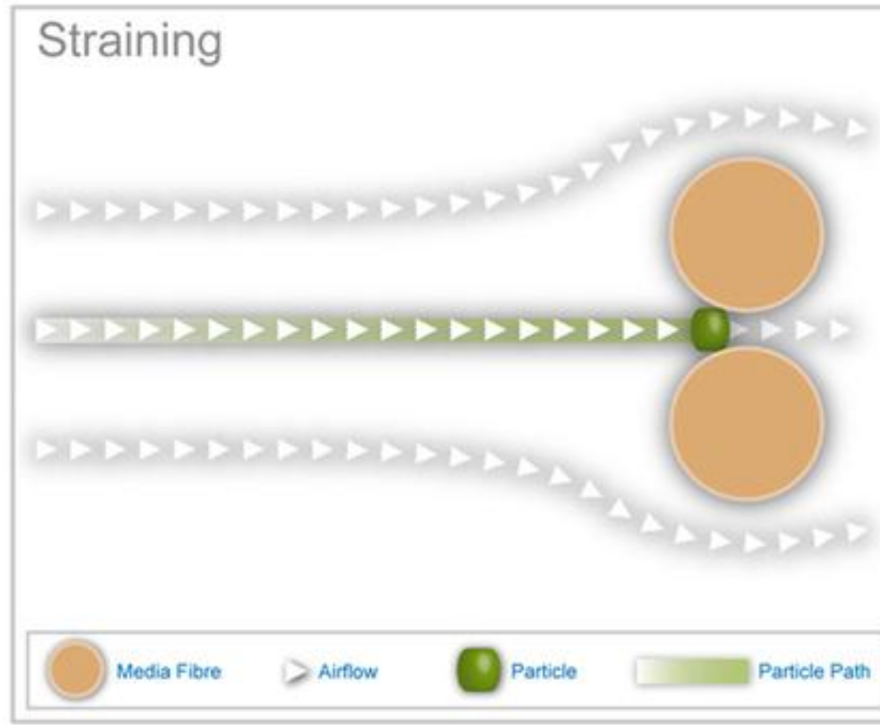
Formation of a thin layer of microbial film around the sand grains ('Schmutzdecke')

Mechanical straining

Principle mechanism of particle removal in filters where thin media are used (i.e. screens or membranes).

No unambiguous criteria has been established yet to determine when mechanical straining becomes important.

Undesirable for granular media filters as head loss will increase rapidly due to the formation of surface mats.



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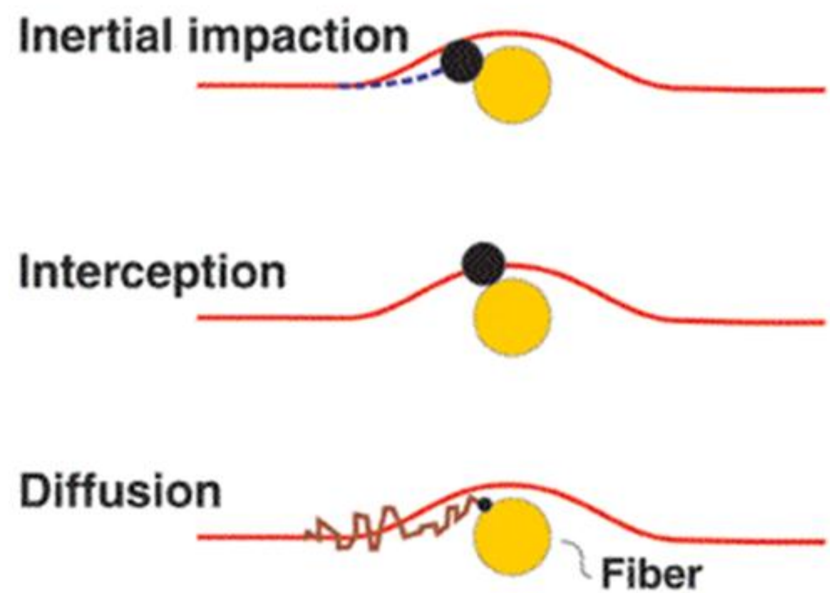
Non straining mechanisms (transport and attachment)

Isolated single-sphere model is used to describe the transport mechanisms.

(A) Impaction: due to inertia of particles.

(B) Hydrodynamic forces: non-uniform shear distribution within pore spaces

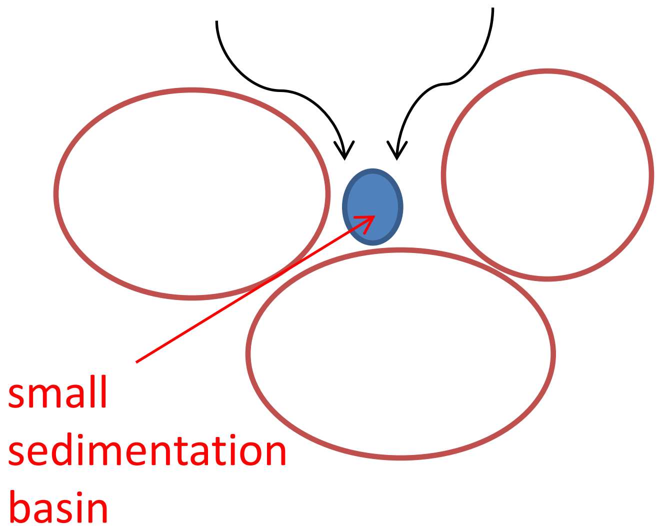
(C) Interception: particles along the streamlines which pass within a distance < radius of the particle.



(D) Diffusion: Particles influenced by Brownian motion.

Non straining mechanisms (transport and attachment)

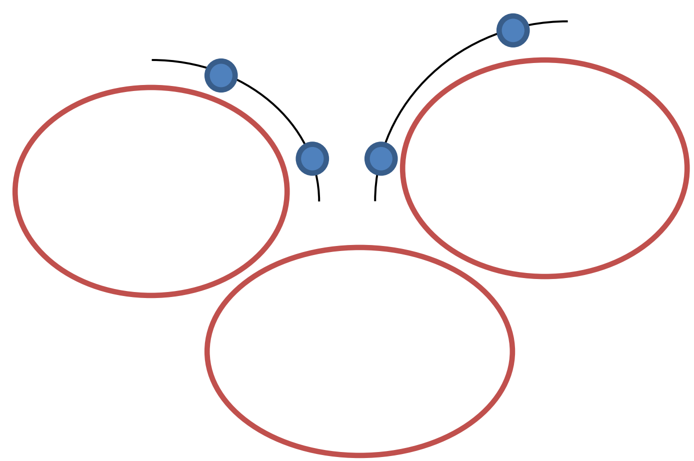
(E) Sedimentation: Particles with density > water will tend to deviate from the fluid streamlines.



(F) Other transport mechanisms:
Van der Waals forces of attraction,
electrostatic attraction

<u>Attachement mechanisms:</u>

(A) Coagulation
(B) Adhesion
(C) Adsorption



Quantifying Particulate collection efficiency

Particle collection efficiency (η) = $\dfrac{\text{Successful number of collisions}}{\text{Total no. of possible collisions in cross-sectional area perpendicular to isolated collector (area } = \pi d_m^2/4)}$

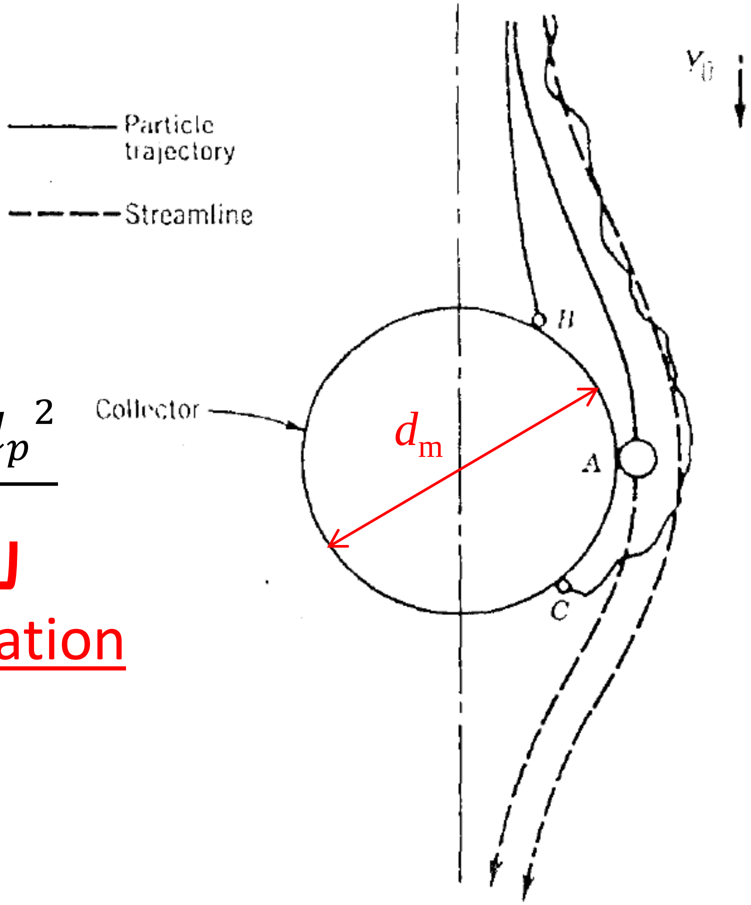
Assuming individual transport efficiencies are additive, all collisions lead to attachment and particle destabilization is complete

$$\eta = 0.9\left(\frac{KT}{\mu d_p d_m V_0}\right)^{2/3} + \frac{3}{2}\left(\frac{d_p}{d_m}\right)^2 + \frac{(\rho_p - \rho) g {d_p}^2}{18\mu {V_0}^2}$$

Diffusion — Interception — Sedimentation

K = Boltzman constant = 1.38×10^{-23} J/°K

T = absolute temp (°K)

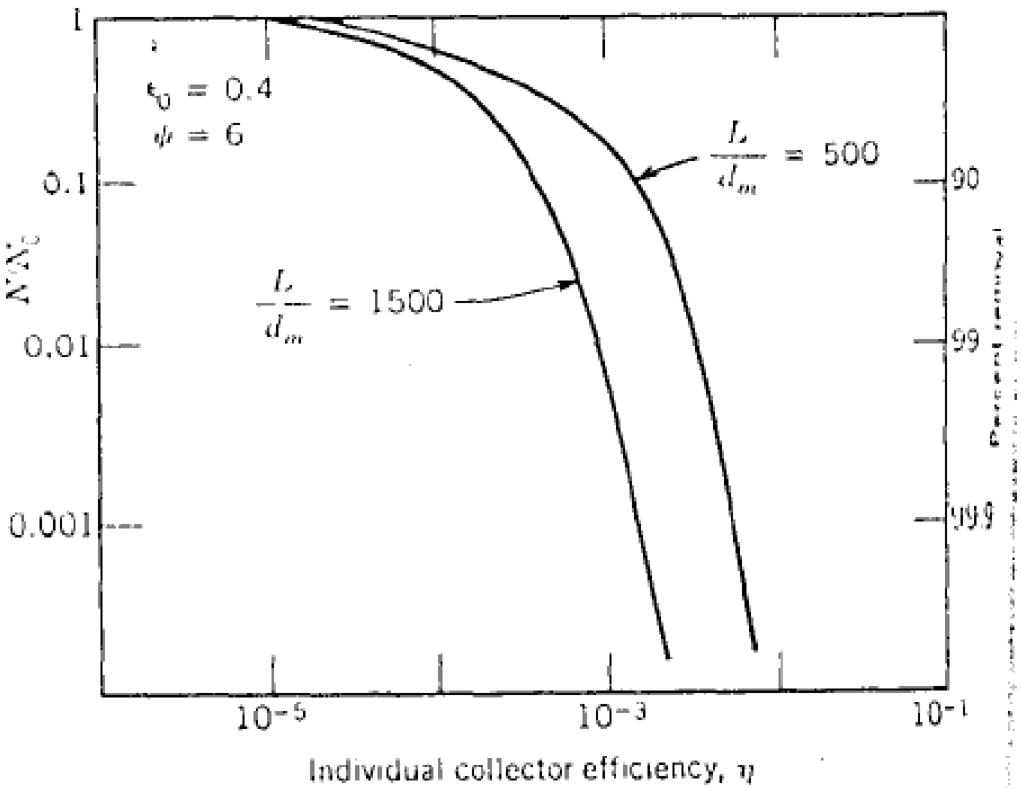


Quantifying Particulate Removal Efficiency

Fraction of particle removed (removal efficiency),

$$\frac{N}{N_0} = exp\left[\frac{-\psi(1-\varepsilon_0)}{d_m} L\eta\right]$$

Ψ = shape factor
ε_0 = initial porosity of granular material
L = media depth

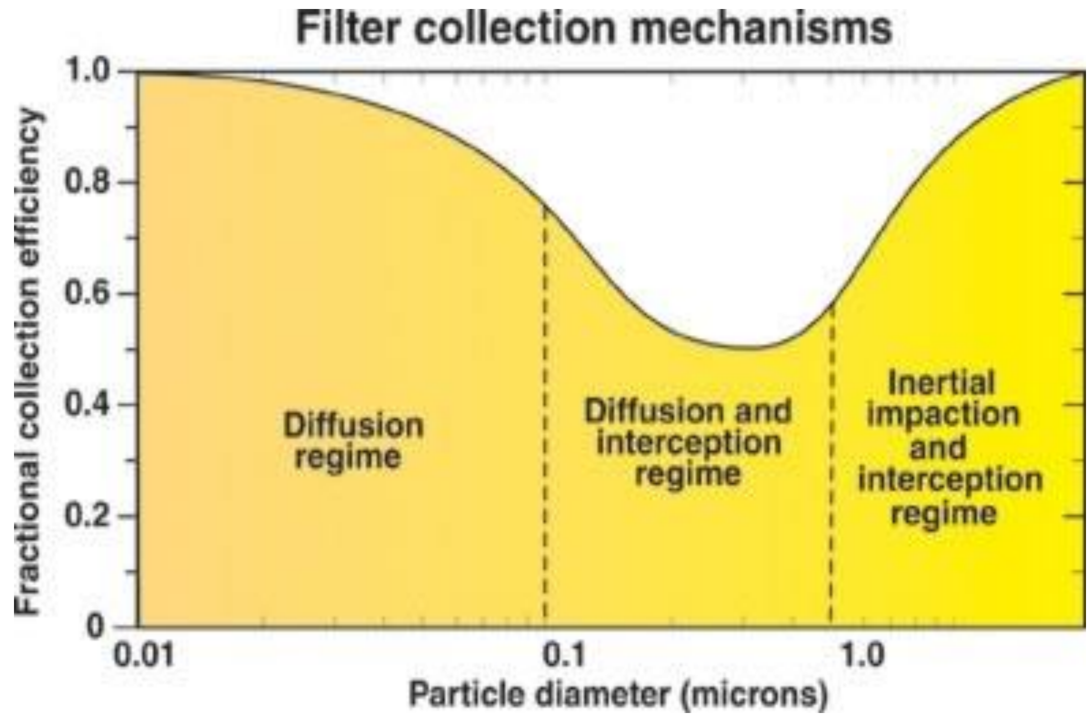


removal efficiency can be increased by

- ❑ decreasing media porosity
- ❑ increasing media depth
- ❑ decreasing media size

Factors affecting collection efficiency

(A) Effect of particle size



(B) Effect of media size and filter velocity: inversely proportional to collection efficiency

Although it is possible to manipulate media size and filter velocity to obtain optimum collection efficiency, adequate destabilization is required for satisfactory filtration.

Factors affecting collection efficiency

Table 7.1. Effects of Different Parameters on Particle Removal Efficiency.[11]

Parameter	Change in Parameter	Change in Particle Removal Efficiency
Influent particle concentration	Increase	No change
Particle density	Increase	Increase
Interstitial velocity (filtration rate)	Increase	Decrease
Filter pore diameter (medium-grain diameter)	Increase	Decrease
Length of the filter pore (depth of the medium)	Increase	Increase
Particle attachment efficiency (degree of destabilization)	Increase	Increase

$$\frac{N}{N_0} = exp\left[\frac{-\psi(1-\varepsilon_0)}{d_m} L\eta\right]$$

Flow through porous media: mathematical analysis

Analogous to flow through a system of interconnected pipes formed by voids in a bed of particles.

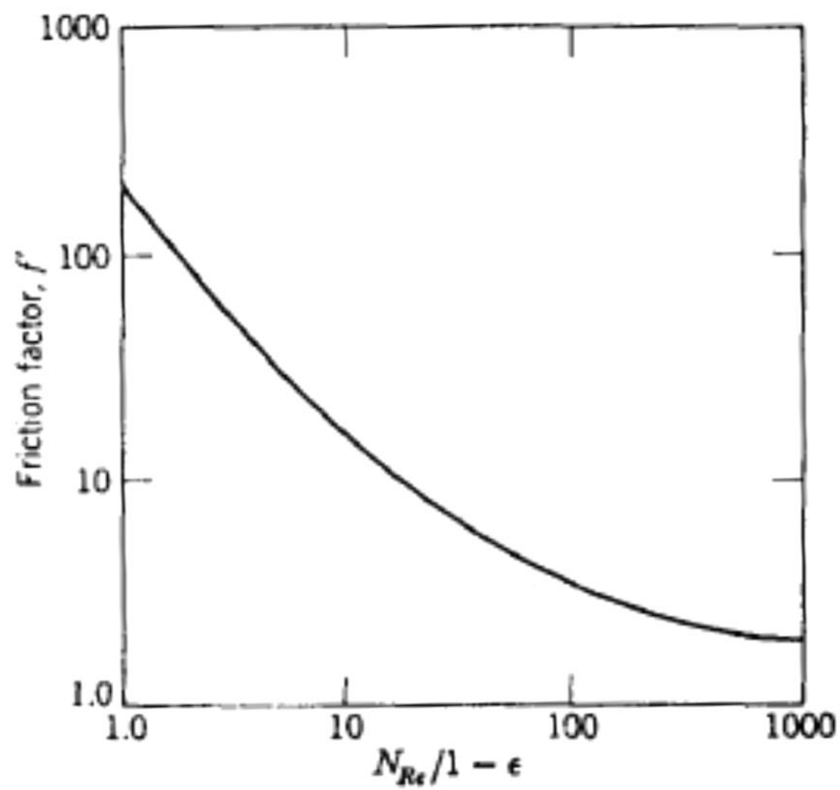
$$h_f = f\frac{L}{4R}\frac{V^2}{2g}$$ [Darcy-Weisbach equation]

h_f = head loss, V = velocity of flow, f = friction factor,
R = hydraulic radius, L = length of pipe

$$h_f = f'\frac{L}{\varphi_S D_P}\left(\frac{1-e}{e^3}\right)\frac{{V_S}^2}{g}$$ [Carman-Kozeny equation]

R = volume of voids/wetted surface area $= \frac{e}{1-e}\frac{V_p}{S_p} = \varphi_S D_P/6$
$V = V_S/e$, e = porosity, V_S = superficial velocity
D_P = particle diameter, φ_S = shape factor f' = friction factor including other constants

Flow through porous media: mathematical analysis



The friction factor f' has been correlated with Reynold's number:

$$f' = 150\frac{1-e}{R_e} + 1.75, \qquad R_e = \frac{\varphi_S D_P V_S \rho}{\mu}$$

Flow through porous media: mathematical analysis

The following Rose equation similar to Carman-Kozeny equation has been developed to compute the head loss in a rapid filter media

$$h_f = f'' \frac{L}{\varphi_S D_P} \left(\frac{1}{e^4}\right) \frac{{V_S}^2}{g}$$

The friction factor f'' has been correlated with Drag coefficient, C_D:

$$f'' = 1.067 C_D, \qquad C_D = \frac{b}{{R_e}^n}$$

Re	b	n
<1.9	24	11.9
1.9 - 500	18.5	0.65
500 – 200,000	0.44	0

For particles of various sizes:

$$h_f = 1.067 \frac{L}{\varphi_S} \left(\frac{1}{e^4}\right) \frac{{V_S}^2}{g} \sum_{i=1}^{n} C_{D,i} \frac{x_i}{D_{P,i}}$$

x_i = weight fraction of particle in the ith layer/fraction of size $D_{p,i}$
$C_{D,i}$ = Drag coefficient, n = number of layers

Flow through Expanded particle bed

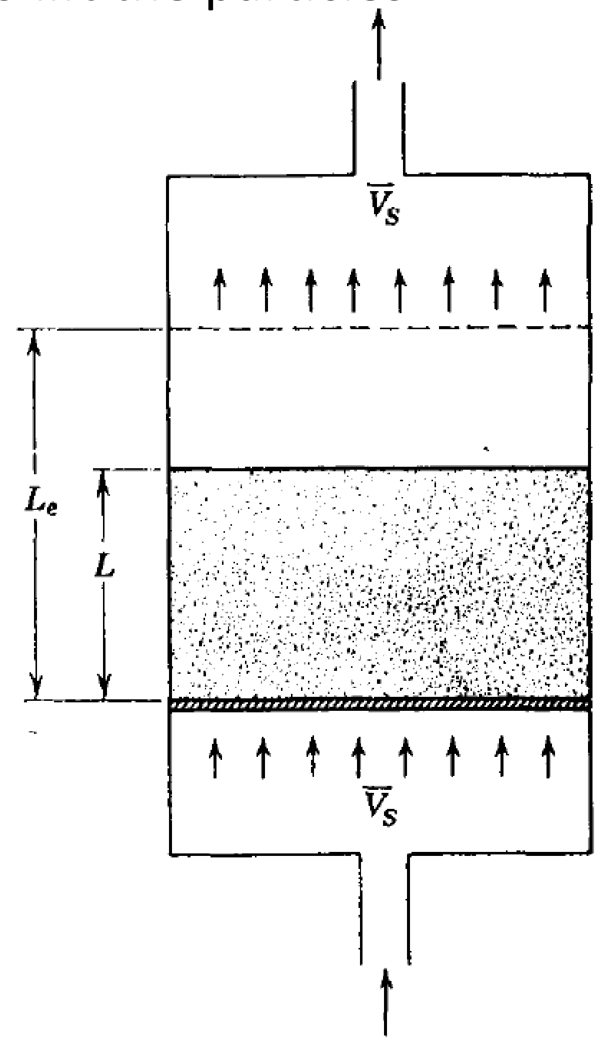
When particles reach to the point of fluidization, the effective weight of the particles is just balanced by the force tending to lift the particles

$$\Delta PA = LA(1-e)(\rho_S - \rho)$$

$$h_f = L(1-e)(\rho_S - \rho)$$

$$L_e = L(1-e)/(1-e_E)$$

ΔP = pressure difference,
A = Area
ρ_S = density of particle
e_E = porosity of expanded bed
L_e = length of expanded bed



Flow through Expanded particle bed

For stratified beds:

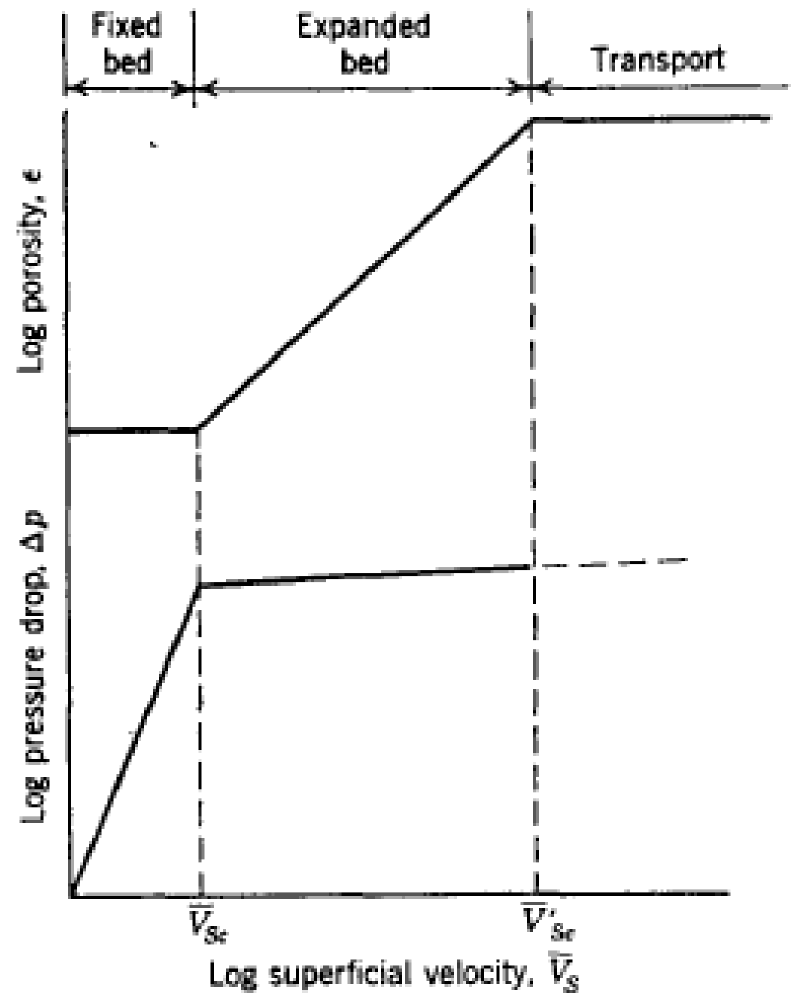
$$L_e = L(1-e)\sum_{i=1}^{n}\frac{x_i}{(1-e_E)_i}$$

e_E can be estimated from V_S and V_t (terminal velocity):

$$e_E = (V_S/V_t)^{0.22}$$

Where, $V_t = \frac{4}{3}\left[\frac{g}{C_D}\left(\frac{\rho_S-\rho}{\rho}\right)D_P\right]^{1/2}$

$$C_D = \frac{b}{{R_e}^n}$$



Week-(14)

MD Ehasan Kabir

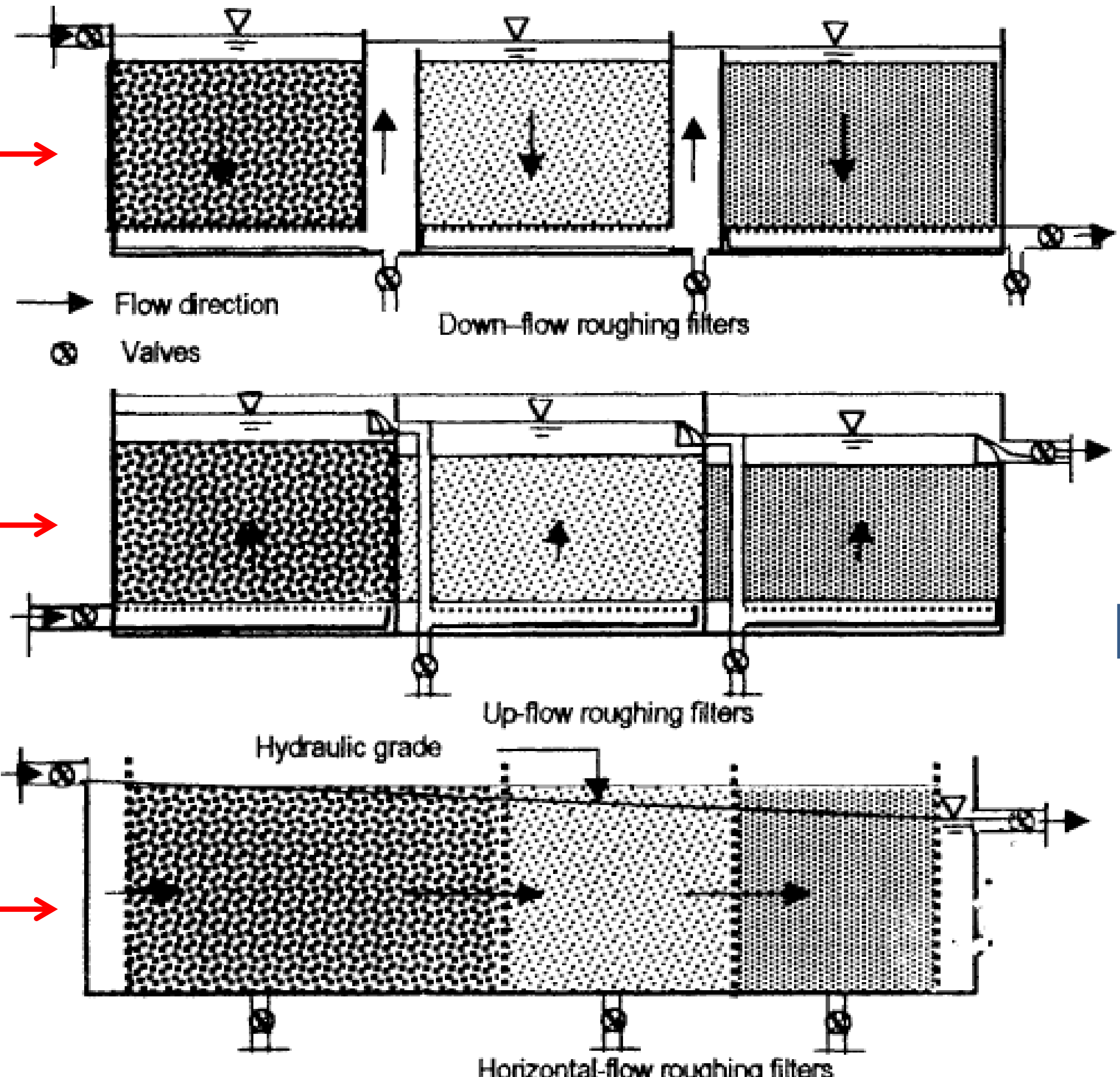
Problem

A sieve analysis of a fine Ottowa sand yields the information recorded in the table below. Compute the initial head loss across a stratified bed of the san, 18 inch deep and with a porosity of 0.41, when water at 45°F is filtered at a rate of 3 gal/min/ft^2. If the sand filter is to be backwashed hydraulically at a rate just sufficient to fluidize the bed, compute the (a) backwash rate (b) the head loss at this rate and (c) depth of the expanded bed

Sieve Numbers, US Sieve Series	Weight Fraction of Particles retained, $\times 10^3$
14 – 20	0.80
20 – 25	4.25
25 – 30	15.02
30 – 35	16.65
35 – 40	18.01
40 – 50	18.25
50 – 60	15.65
60 – 70	9.30
70 - 100	2.07

Roughing filtration: layout and design

Three types



Purpose:
Pretreating water with high turbidities

Decreasing gravel size

Roughing filtration: cleaning and efficiency

Cleaning:

Either hydraulically (shock drainage) or manually

Up-flow filters possess a favorable layout

Excavation of filter bed, washing and refilling

Efficiency:

- SS removal upto 95% and turbidity removal of 50-90% have been reported
- Color removal 20-50% and faecal coliform reduction 0.65 – 2.5 log units
- 50% removal of iron and manganese has also been achieved

Roughing filtration: advantages and disadvantages

Advantages:

- ❑ Allows deep penetration of filter materials
- ❑ Have large silt storage capacity
- ❑ Often used before SSF because of their effectiveness in removing SS
- ❑ More effective as a pretreatment than pre-sedimentation for raw water to the physical standards required by SSF

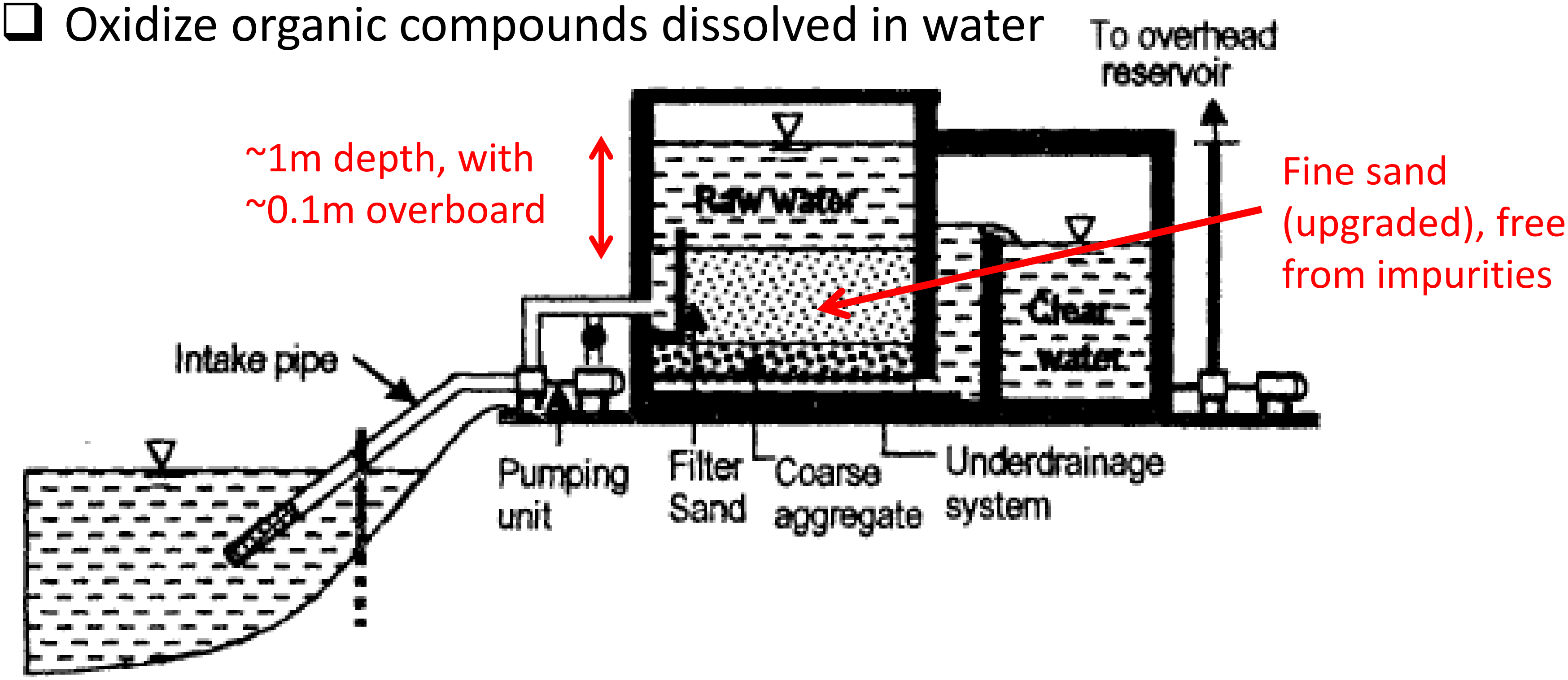
Disadvantages:

- ❑ Limited to average turbidity of 20-150 NTU to prevent frequent clogging

Slow Sand Filtration (SSF)

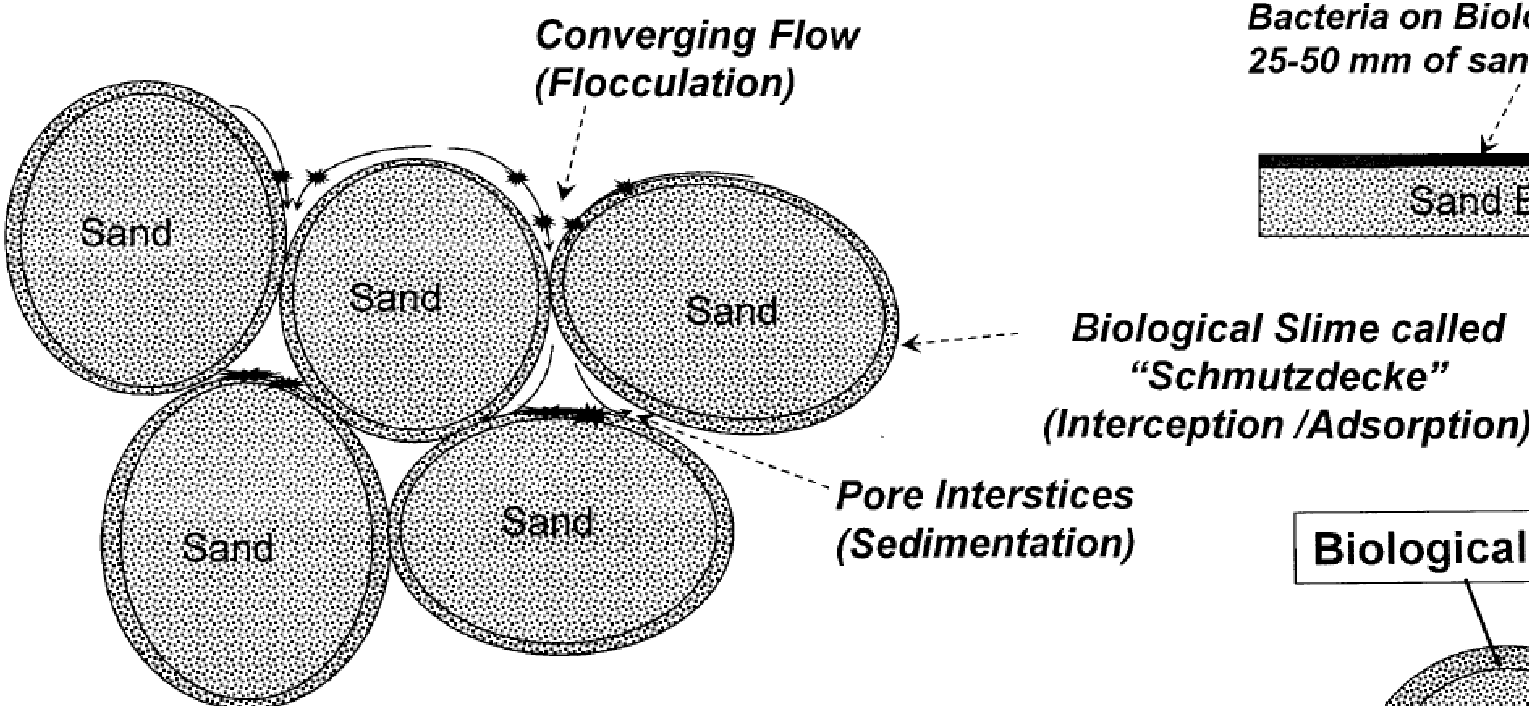
Purpose:

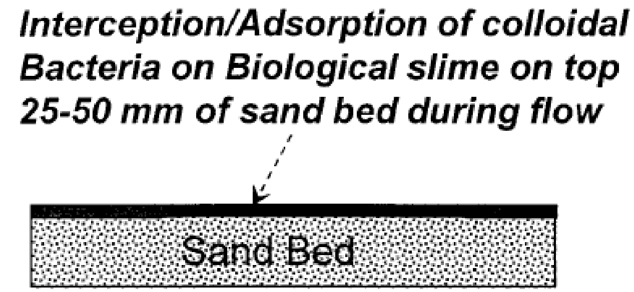
- ❑ Reduce the number of microorganisms in water
- ❑ Retain fine organic and inorganic solid matters
- ❑ Oxidize organic compounds dissolved in water

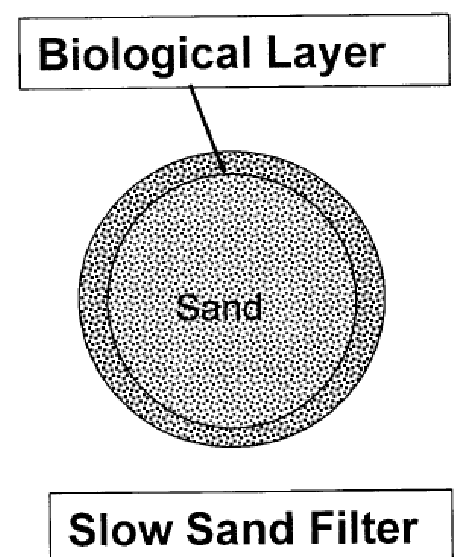


Suitable for the development of surface water-based water supply systems in developing countries

Particle Removal Mechanism in SSF







SSF Characteristics

- Very low rate of filtration
- High removal of turbidity (80-85%) and color (95-99.9%)
- No pretreatment generally required for water <30NTU
- Not very effective in removing colloidal matters, treating water >30NTU or with excessive algal growth
- Low cost operation and maintenance
- 2-4 weeks ripening period required after installation, however it can regain full biological activities (formation of ‘Schmutzdeke’) after a few hours of cleaning thereafter.
- Cleaning done by removing scraping and removal of the top 1.5-2 cm of sand
- Perform best under continuous operation and constant flow conditions

Limitations of SSF

SSF design criteria

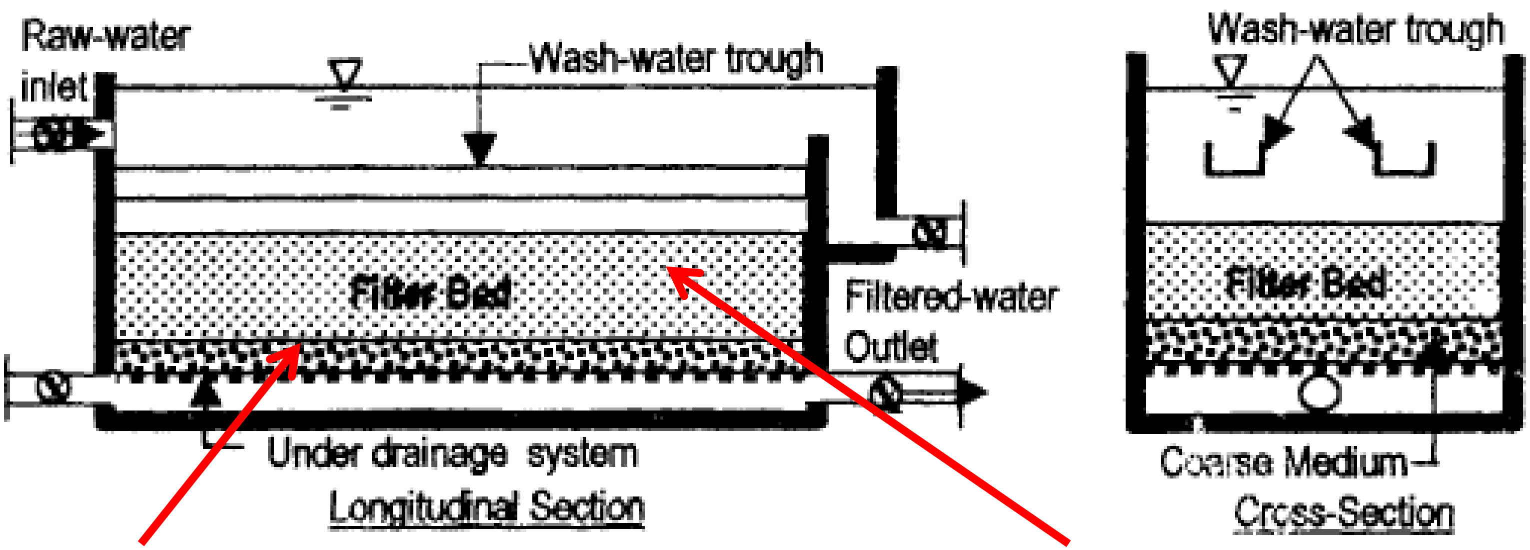
- Filtration rate 0.1 – 0.2 m/hr
- box height 2 m
- Sand gradation: d_{10} between 0.1 – 0.3 mm, d_{60}/d_{10} <3.
- Sand quality: clean sand free from clay, silt and organic matter
- Underdrain system should have a gravel layer of 0.3 – 0.5 m
- Number of rectangular filters required for a plant:

$$n = 0.5\sqrt[3]{A}$$

A = total surface area in m^2 computed on the basis of filtration rate and design water demand.

Rapid Sand Filtration (RSF)

Higher filtration rate is achievable because of the coarse sand (d_{10} = 0.4-1.2 mm) and relatively uniform-sized particles that are used as the filter medium

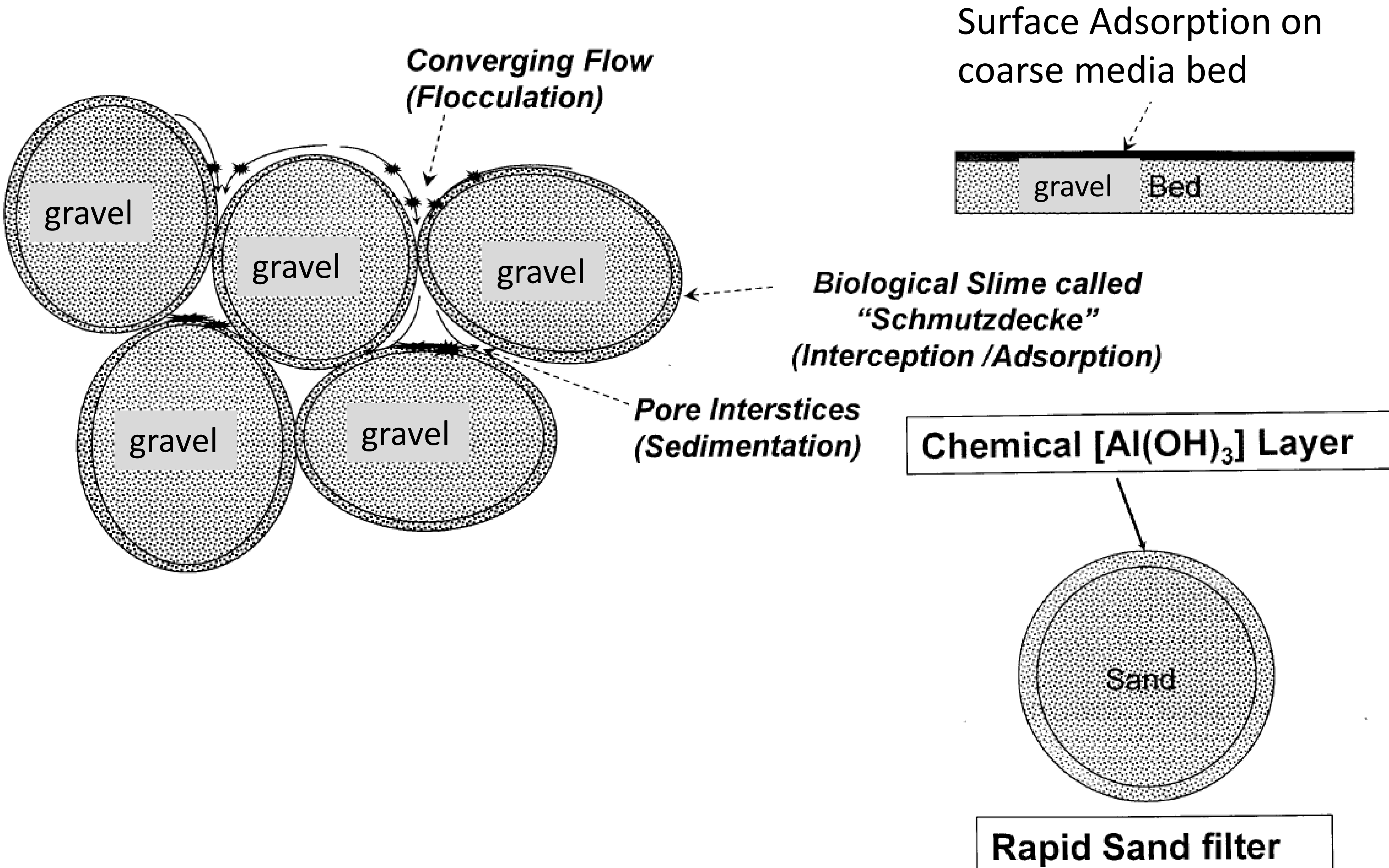


Graded gravel, 0.5 m thick

Coarse sand layer, 1 m thick

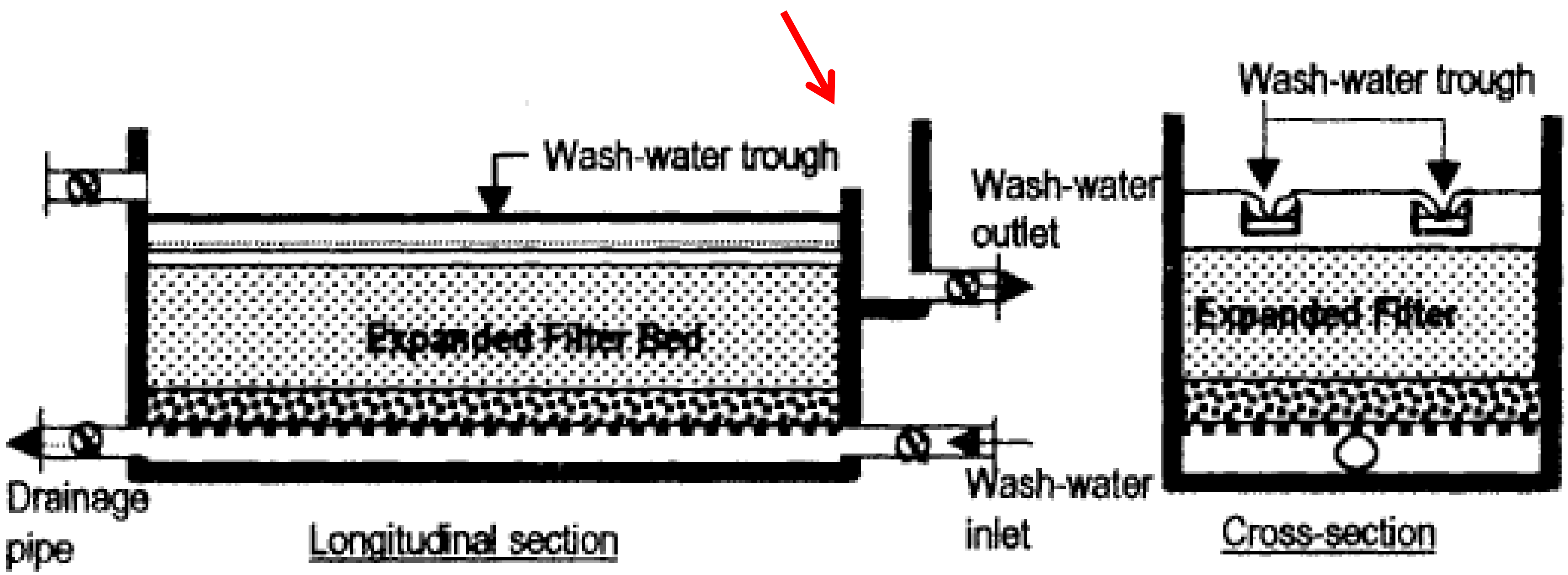
Can be both gravity type and pressure type

Particle Removal Mechanism in RSF



Characteristics of RSF

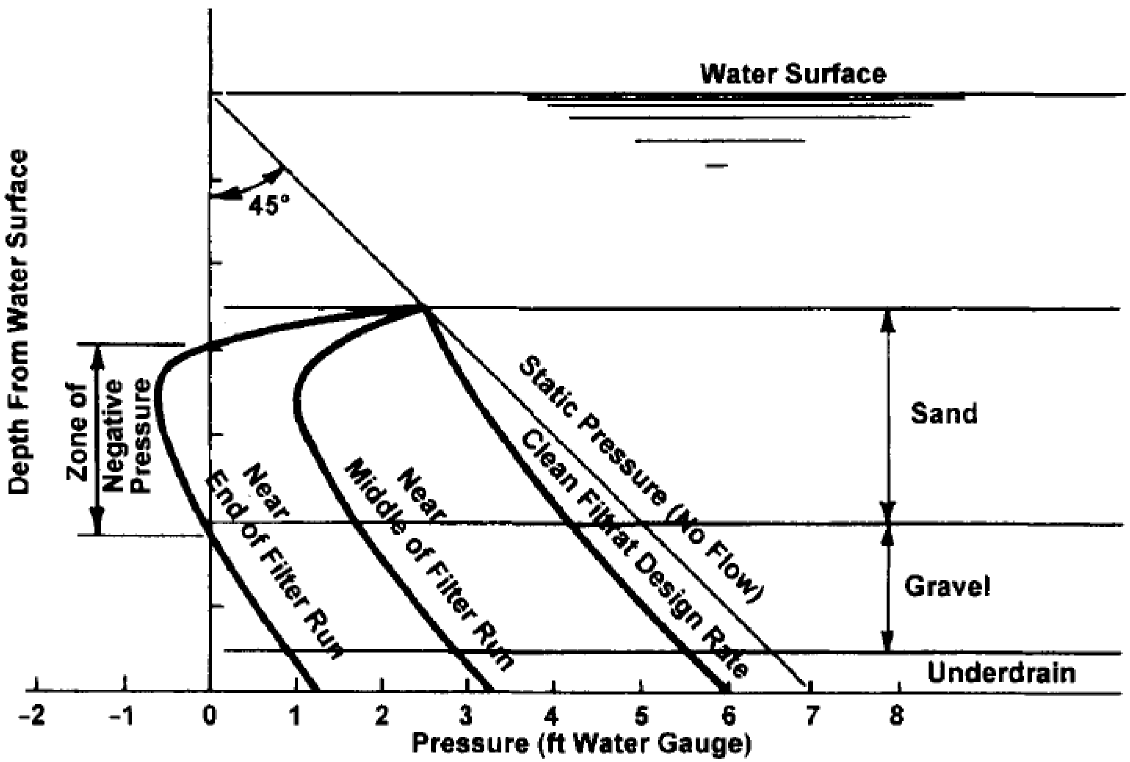
- High filtration rates 5-15 m^3 per m^2 per hour
- High removal of turbidity (80-85%) and color (85-95%)
- Pretreatment such as coagulation, flocculation and sedimentation are required
- Suitable for all types of turbid and colored water
- Relatively high cost of operation and maintenance.
- Cleaning of filter bed by **backwashing**



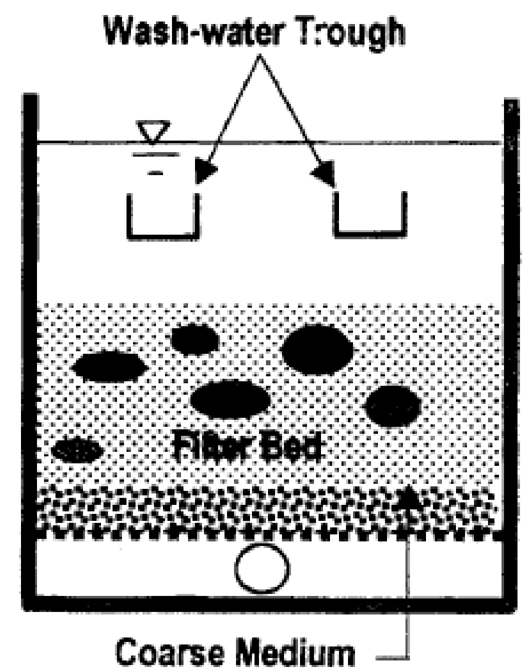
Back washing cycle

Operational difficulties in RSF

(A) Negative head and air binding

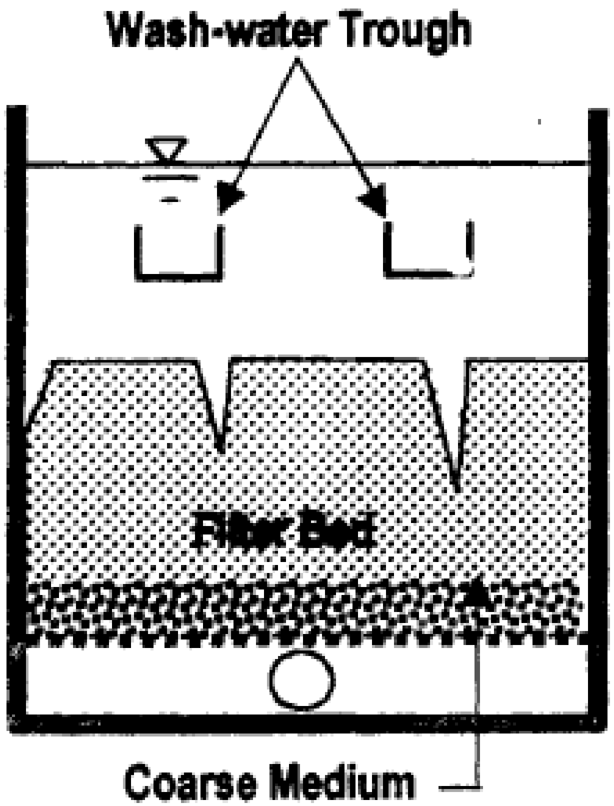


(B) Formation of mud balls

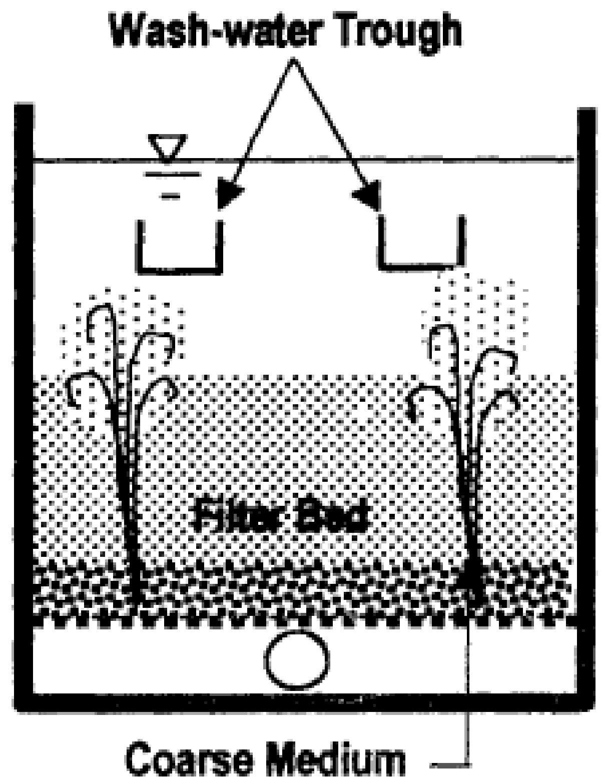


Operational difficulties in RSF

(C) Cracking of filter bed



(D) Jetting and sand boils



(E) Sand Leakage

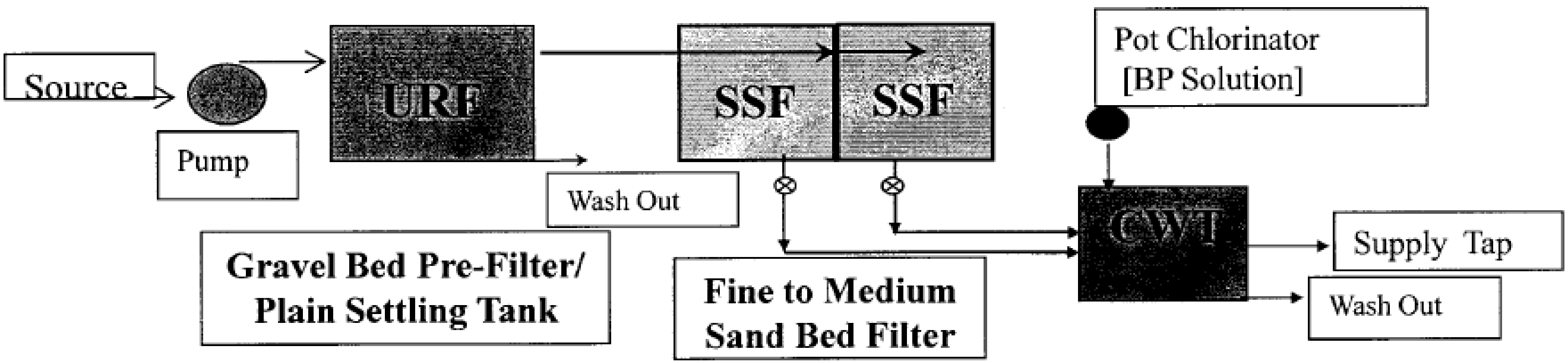
Design considerations of RSF

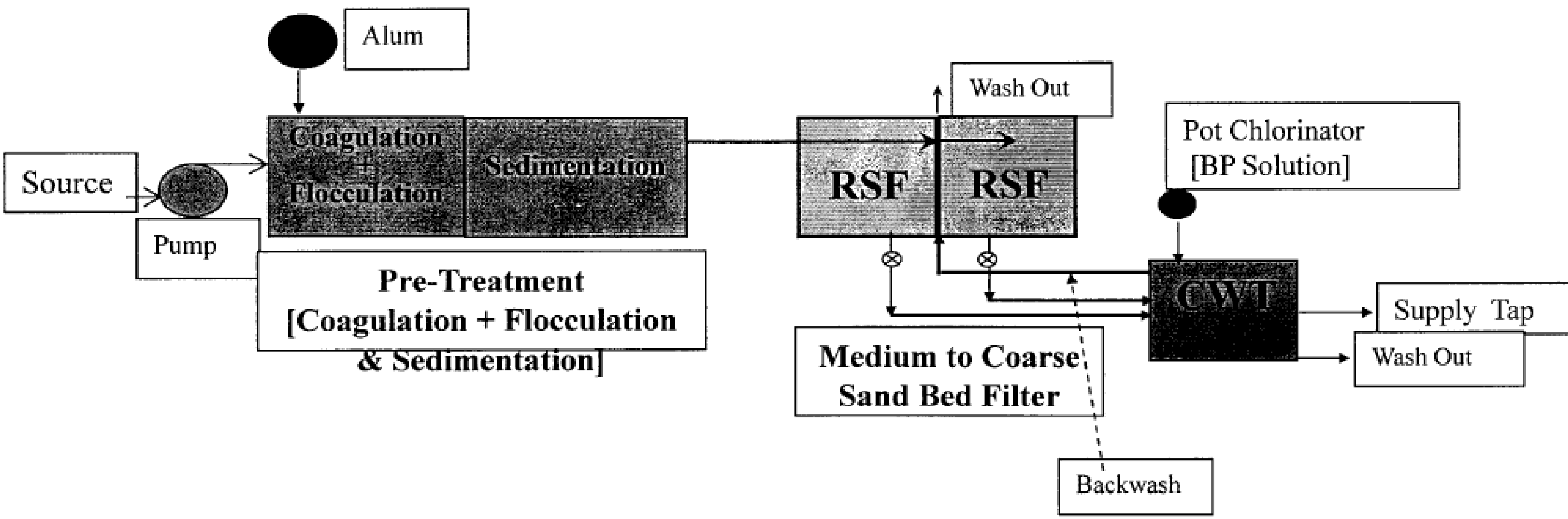
- Economy in construction and operation
- Provision of future consideration
- Soil conditions, foundation and structural stability
- Flexibility in operation
- Compactness, minimization of head losses and operational
- Utilization of topography to minimize earth work and to make proper use of gravity
- Size of the filter is determined by the required capacity of the plant

$$N = 0.04\sqrt{Q}$$

N is the number of units and *Q* is the plant capacity in m^3 per day

General features of SSF and RSF





Characteristic Differences among SSF, RSF and RF

Characteristics	SLOW SAND FILTER	RAPID SAND FILTER	UF ROUGHING FILTER
Suitability :	Turbidity < 50 NTU)	Turbidity > 50 NTU	Turbidity 50-150 NTU
Pre-treatment :	URF/P. Sediment.	Coag., Floc. & Sed.	Not required/DRF
Rate of filtration :	0.1 - 0.4 m/h	5 -10 m/h	1 -2 m/h
Ripening :	0.25day -30days	5 -10 minutes	3 -10 days
D_{10} :	0.1-0.3 mm	0.45-0.55mm	5 - 8 mm
U (Coef.) :	2 -3	1.2 -1.7	1.7 -2.5
Thickness :	1.0 m - 1.4 m (FMS)	0.3 m to >1.0 m (MCS)	0.6 -1.0 m (Gravel)
Under drain:	Slotted pipe grid	Gravel & Perf.Tiles	Perforated RCC slab
Cleaning :	Surface Scraping	Back washing	Flushing drain out
Filter run :	40 - 60 days	1 - 3 days	21 -28 days
Area :	Large in size	Small in size	Moderate in size

Problem

A rapid sand filter is to be designed for a capacity of 27000 m^3/day. What should be the number and size of the units. Calculate the percentage of filtered water required to wash the filter bed and the capacity of the wash water tank.

Assume:

Rate of filtration: 5 $m^3/hr/m^2$

rate of washing: 35 $m^3/hr/m^2$

Length of the filter run: 24 hours including 5 min for filter washing and 10 min for resettlement of sand bed

Process Selection

1. Characteristics of the media depending on the particular type of application

TABLE 8.2 Typical Grain Sizes for Different Applications

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

Process Selection

2. Different filtering devices/media must be overviewed.

- Screens – 1-100 μm (effective size opening)
- Diatomaceous earth – 7-50 μm
- Granular – 0.1 - 10 mm

3. Comparison with other solid-liquid separation processes

- screening
- sedimentation
- Flotation
- Membrane filtration

Selection process is usually based on experience

Process Selection

4. Physical characteristics of the particulates to be removed

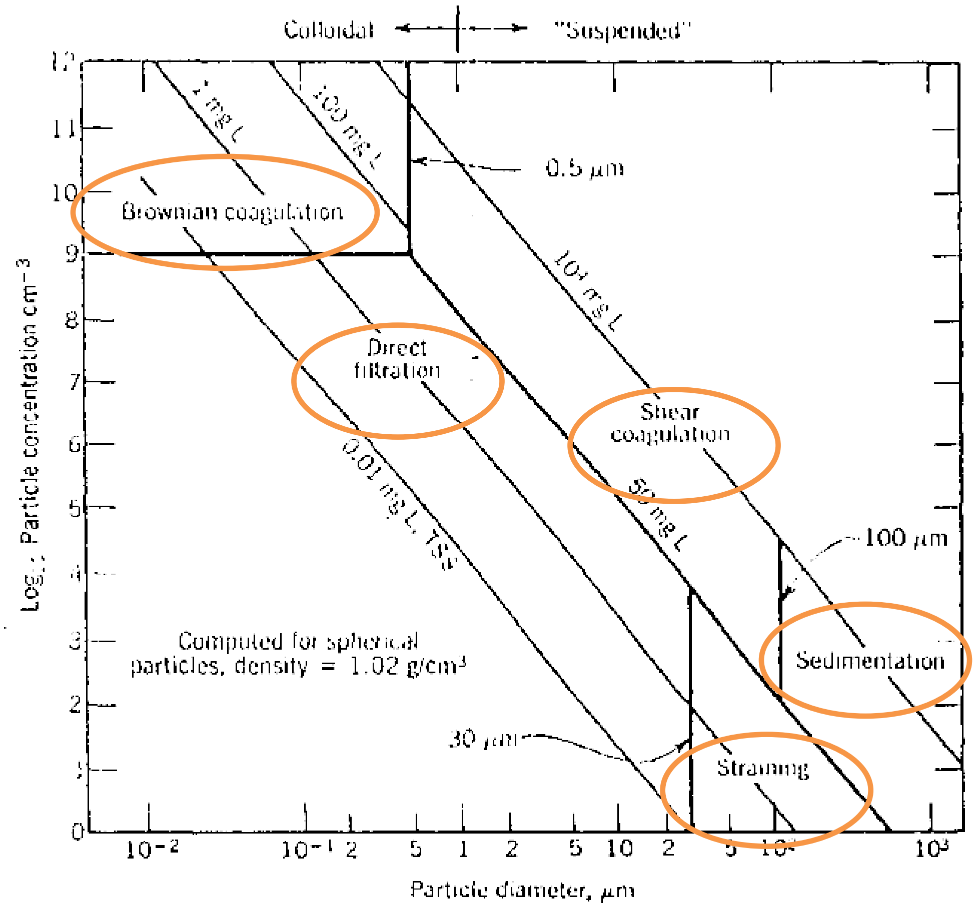
- Initial number and mass concentration
- Average size characterizing the distribution

Process	Avg size (μm)	SS (mg/L)
Gravity Sedimentation	>100	>50
Screening	~30	<50
Filtration using granular media without sedimentation	<30	<50
Coagulation sedimentation prior to filtration	<30	>50

For high algae concentration, microscreens are used before granular media filtration

4. Physical characteristics of the particulates to be removed

- Initial number and mass concentration
- Average size characterizing the distribution



Process Selection

Example

- When particle size↓, turbidity ↓ ------ use SSF
- When particle size↑, turbidity ↑ ------ use RSF but with prior sedimentation and coagulation

5. Other considerations for ultimate selection of design criteria

- Analytical models of the process
- Previous experience
- Pilot studies
- Published literature

Week-(15)

MD Ehasan Kabir

Fluoride Removal

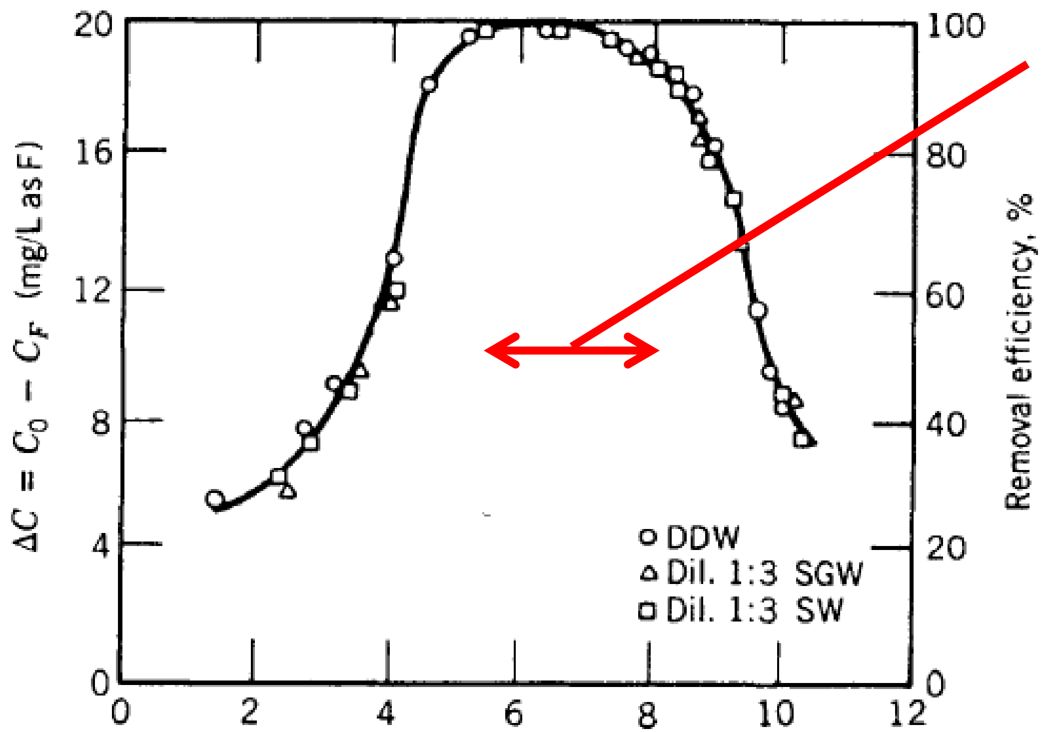
Removal by Ion Exchange using Activated Alumina

Factors affecting removal by Activated Alumina

Other removal techniques (Lime Softening and Alum Coagulation)

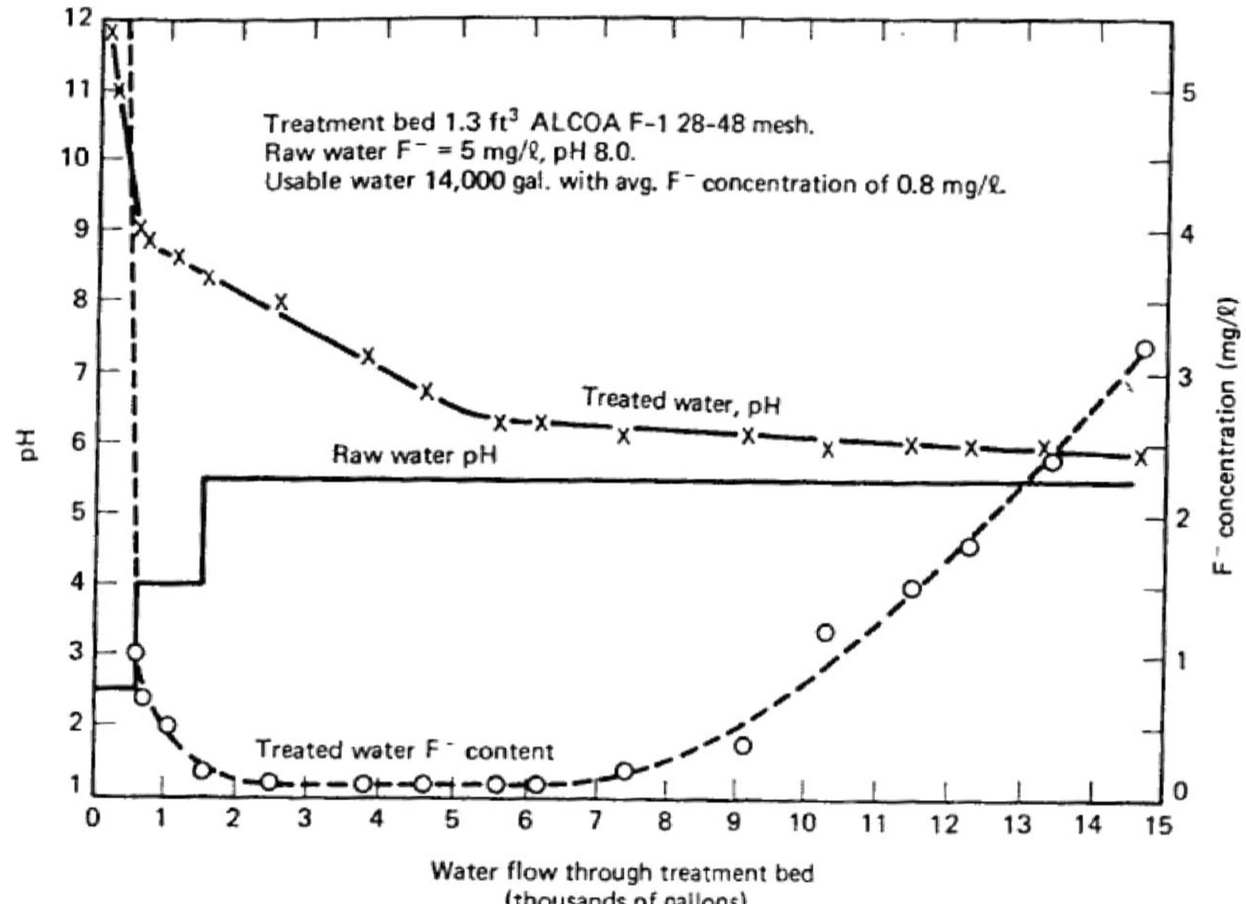
Removal by Activated Alumina

- Activated Alumina is a granular, highly porous material (consisting of Al_2O_3) and Fluoride is removed as a result of **ion exchange**
- Activated Alumina can be regenerated with NaOH
- Optimum removal of Fluoride is pH-dependent



Removal by Activated Alumina

- Steps taken to elute the Fluoride from Activated Alumina
  - (a) Backwash (10 – 15 min)
  - (b) Regeneration (1 – 1.5 hr, 0.25 – 3 gpm/ft3, 0.5 – 2% NaOH)
  - (c) Neutralization (using pH adjusted raw water)



Other removal techniques: Lime Softening

By forming an insoluble precipitate and by coprecipitation with $Mg(OH)_2$

$$Ca(OH)_2 + 2HF \rightarrow CaF_2\downarrow + 2H_2O$$

To estimate the magnesium required, Culp et al. developed this equation:

$$F_{residual} = F_{initial} - (0.07F_{initial} \times \sqrt{Mg}$$

Problems:

- ❑ Low solubility of CaF_2 (10 mg/L at pH 10)
- ❑ Large amounts of Magnesium required (100 mg/L to reduce Fluoride from 5 to 1.5 mg/L)
- ❑ Large amounts of sludge produced

Other removal techniques: Alum Coagulation

By adsorption on to Al(OH)3 particles, which is formed from the reaction between alum and alkalinity of water:

$$Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3CaSO_4 + 14H_2O + 6CO_2$$

Problems:

- ❑ Large amounts of Alum required (250 mg/L to reduce Fluoride from 3.6 to 1.4 mg/L)
- ❑ Large amounts of sludge produced

Week-(16)

MD Ehasan Kabir

Gas Transfer

Absorption and desorption, applications

Two film theory of gas transfer

Estimation of gas flux and optimizing gas transfer

Factors affecting solubility and dispersion

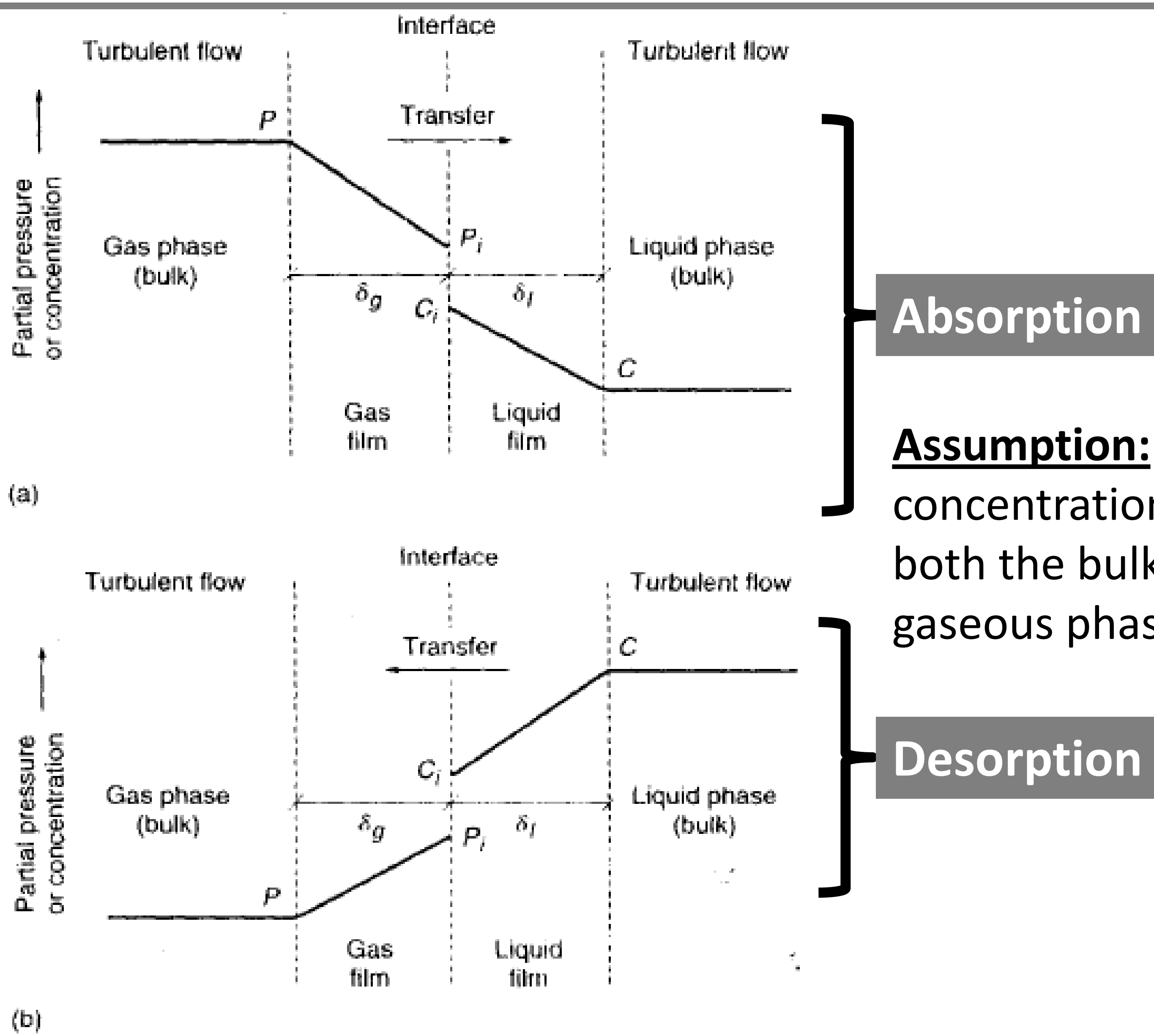
Different aeration techniques

Gas transfer, absorption and desorption

A physical phenomenon in which gas molecules are exchanged between a liquid and a gas at a gas-liquid interface.

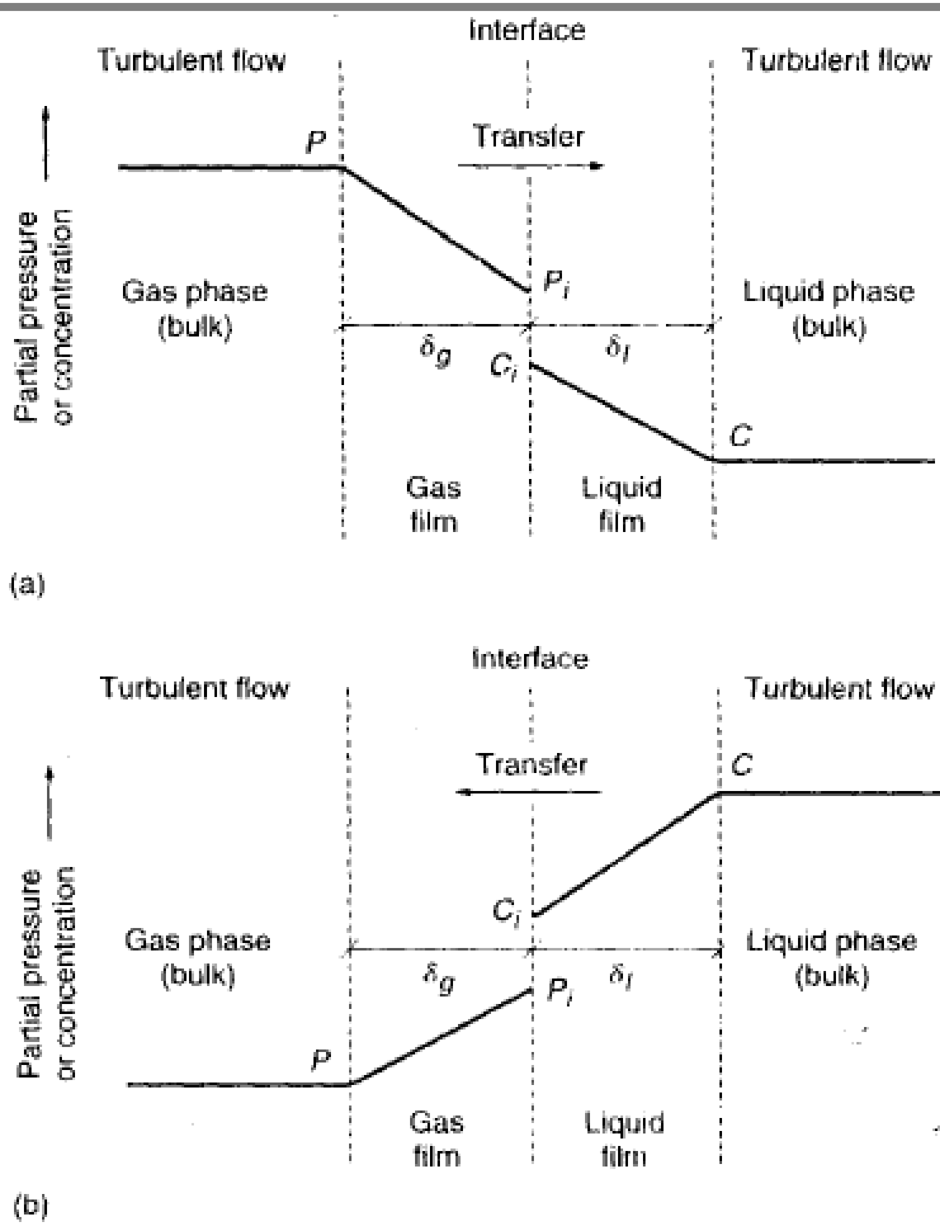
Examples	Water treatment objectives	
O_2, Cl_2	Oxidation of Fe^{2+}, Mn^{2+}, S^{2-}	Absorption
O_3	Disinfection, color removal, oxidation of organics	
ClO_2	Disinfection	
CO_2	pH control	
SO_2	Dechlorination	
NH_3	Chloramine formation for disinfection	
CO_2, O_2	Corrosion control	Desorption
H_2S	Odor control	
NH_3	Nutrient removal	
VOC	Taste and odor control, removal of carcinogens	

The two film theory of gas transfer



<u>Assumption:</u>
concentration and pressure in both the bulk liquid and gaseous phase is uniform

The two film theory of gas transfer



<u>Mass flux for gas absorption</u>

$$r = \frac{dW}{A.\,dt} = k_G(P_G - P_i) = k_L(C_i - C_L)$$

k_G, k_L = mass transfer coefficients for gas and liquid

Mass transfer can be enhanced by reducing the thickness of the film (either gas or liquid)

The two film theory of gas transfer

<u>If mass tranfer is governed by the liquid film</u>

$$r = K_L(C_S - C_L) = k_G(P_G - P_i) = k_L(C_i - C_L)$$

overall liquid mass transfer coefficient

Concentration at the interface in equilibrium with P_G

Henry's Law can be applied at the interface

$$P_i = HC_i \qquad P_G = HC_S$$

H = Henry's constant

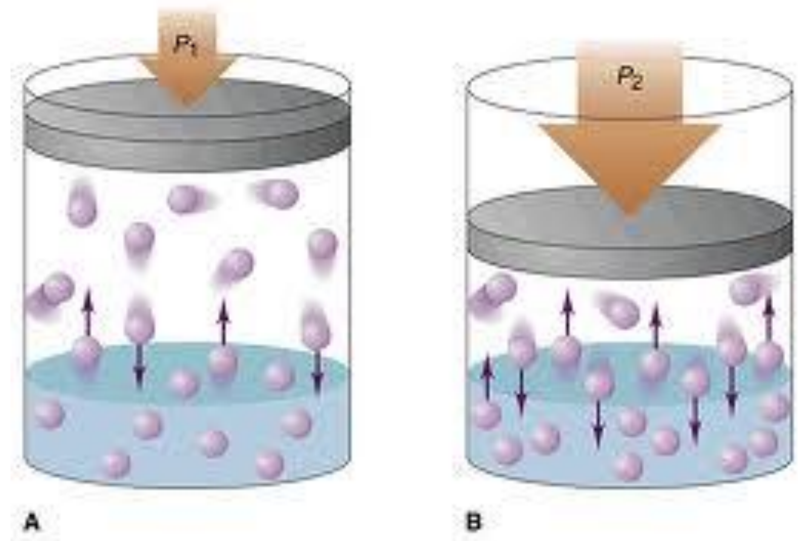
The net driving force:

$$(C_S - C_L) = (C_S - C_i) + (C_i - C_L)$$

$$1/K_L = 1/k_L + 1/HK_G$$

resistance from liquid

resistance from gas



The two film theory of gas transfer

$$1/K_L = 1/k_L + 1/HK_G$$ Governed by liquid film

$$1/K_G = 1/k_G + H/K_L$$ Governed by gas film

Relationship between overall liquid and gas phase transfer coefficients:

$$1/K_L = 1/HK_G$$

If H↑ : liquid phase resistance controls mass transfer
If H↓ : gas phase resistance controls mass transfer

Solubility and gas transfer

If the gas is highly soluble (e.g. NH_3):

Passage of gas molecules across the gas film is the controlling factor.

$$r = \frac{dW}{A.dt} = k_G(P_G)$$, P_i is negligible

Moving or stirring the gas will enhance transfer

If the gas is weakly soluble (e.g. O_2, N_2 and CO_2):

Passage of gas molecules across the liquid film is the controlling factor.

$$r = \frac{dW}{A.dt} = k_L(C_S - C_L)$$

Moving or stirring the liquid will enhance transfer

Gases of intermediate solubility (e.g. H_2S):

Effect of both films are important.

$$r = \frac{dW}{A.dt} = K_L(C_S - C_L)$$

overall liquid mass transfer coefficient

Estimation of gas flux and optimization

$$r = \frac{dW}{A.dt} = K_L(C_S - C_t)$$

Rate of mass transfer per unit volume per unit time

$$r_v = K_L\frac{A}{V}(C_S - C_t) = K_L a(C_S - C_t) = \frac{dC}{dt}$$

interfacial area

Integrating over time:

$$(C_t - C_0) = (C_S - C_0)[1 - exp(-K_L at)]$$

Problem: Dechlorinated secondary effluent is placed in a storage basin until needed for reuse. The initial DO is 1.5 mg/L, estimate the time required for the DO to reach 8.5 mg/L due to surface reaeration, assuming the water in the storage basin is circulated and not stagnant. Assume K_L = 0.03 m/h, C_S = 9.09 mg/L. The surface area of the storage basin is 400 m^2 and depth is 3m

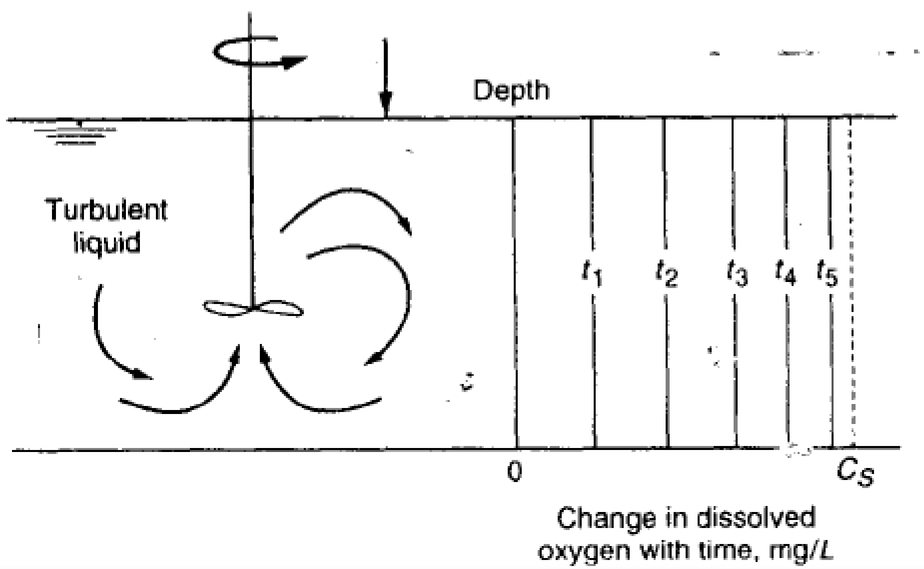
Factors affecting solution and dispersion of gas in liquid

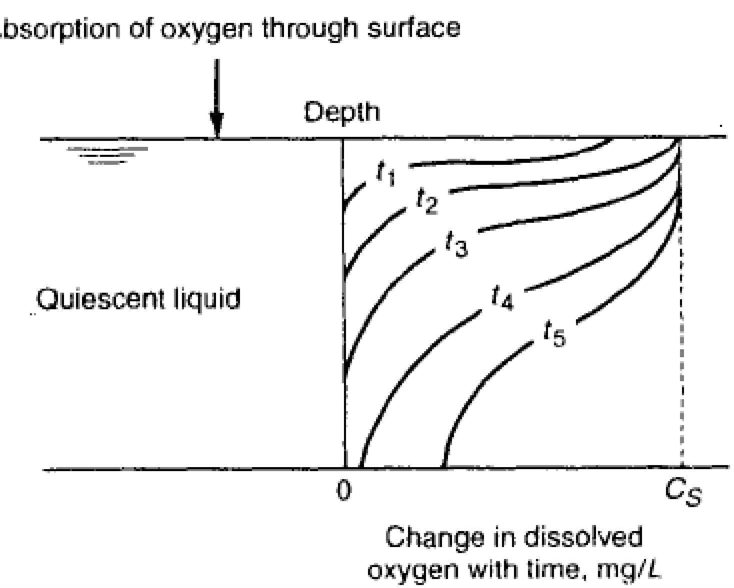
Solubility of gas depends on:

a) Its partial pressure in the atmosphere in contact with water
b) Water temperature
c) Presence of impurities

Rate of gas dispersion in water depends on:

a) Molecular diffusion b) Eddy diffusion by convection c) Eddy diffusion by agitation





Objectives of aeration

Examples	Water treatment objectives	
O_2, Cl_2	Oxidation of Fe^{2+}, Mn^{2+}, S^{2-}	Absorption
O_3	Disinfection, color removal, oxidation of organics	Absorption
ClO_2	Disinfection	Absorption
CO_2	pH control	Absorption
SO_2	Dechlorination	Absorption
NH_3	Chloramine formation for disinfection	Absorption
CO_2, O_2	Corrosion control	Desorption
H_2S	Odor control	Desorption
NH_3	Nutrient removal	Desorption
VOC	Taste and odor control, removal of carcinogens	Desorption

How to optimize gas transfer

$$(C_t - C_0) = (C_S - C_0)[1 - exp(-K_L at)]$$

<u>Gas transfer can be optimized by:</u>

a) Increasing interfacial area
b) Preventing buildup of thick interfacial films
c) Inducing a long time of exposure
d) Ventilating the aerator to maintain the highest possible driving force $(C_S - C_t)$

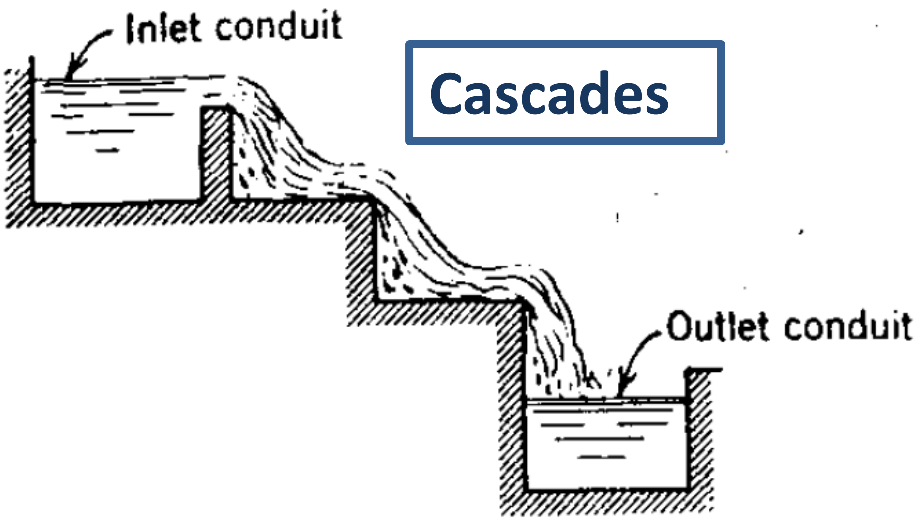
<u>Four types of aerators:</u>

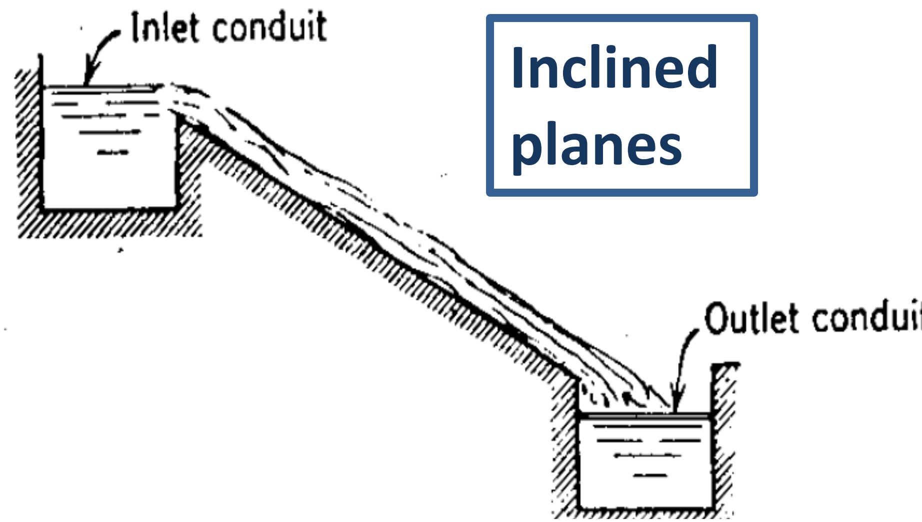
1. Gravity aerators
2. Spray aerators
3. Diffusers
4. Mechanical aerators

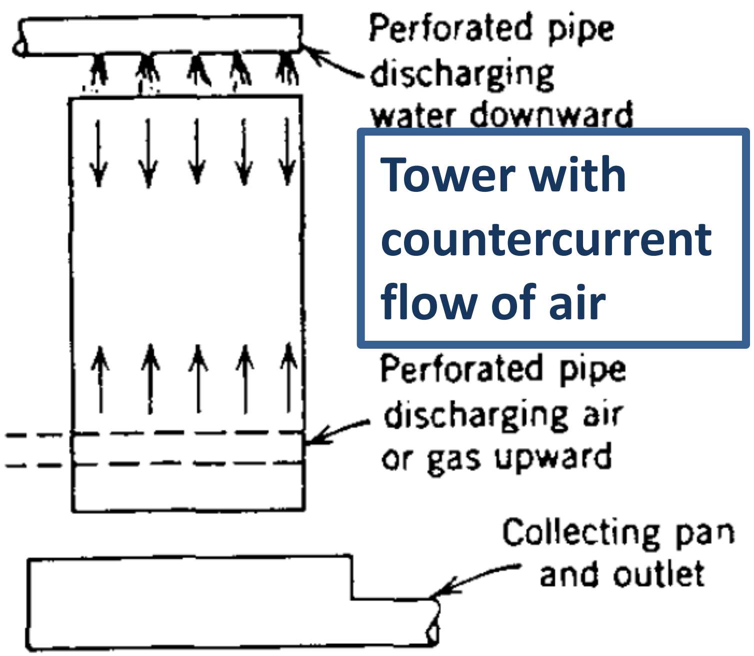
Gravity aerators and Spray aerators: Used for water treatment

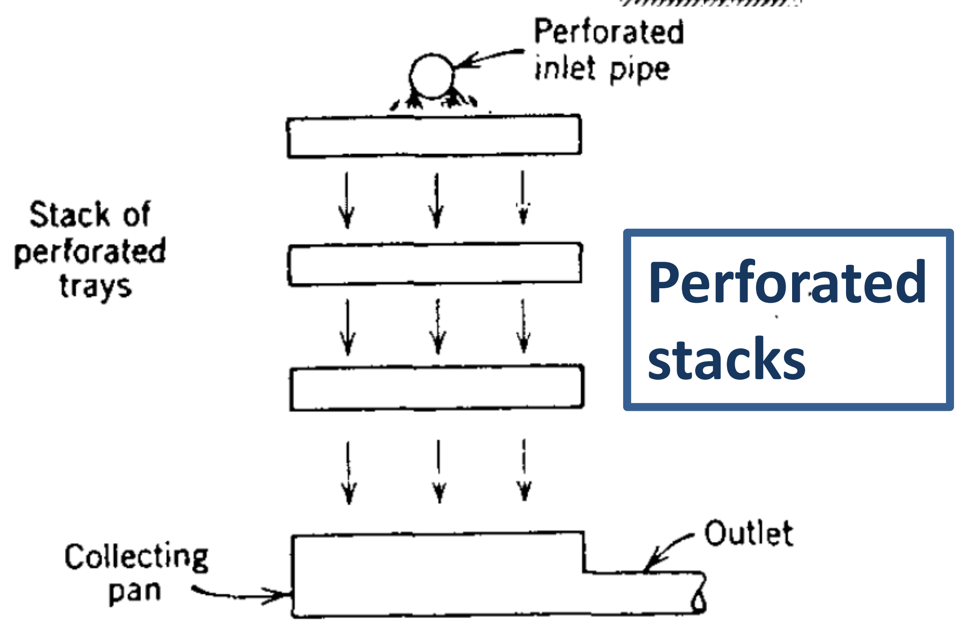
Diffusers and Mechanical aerators: Used for wastewater treatment

Gravity aerators

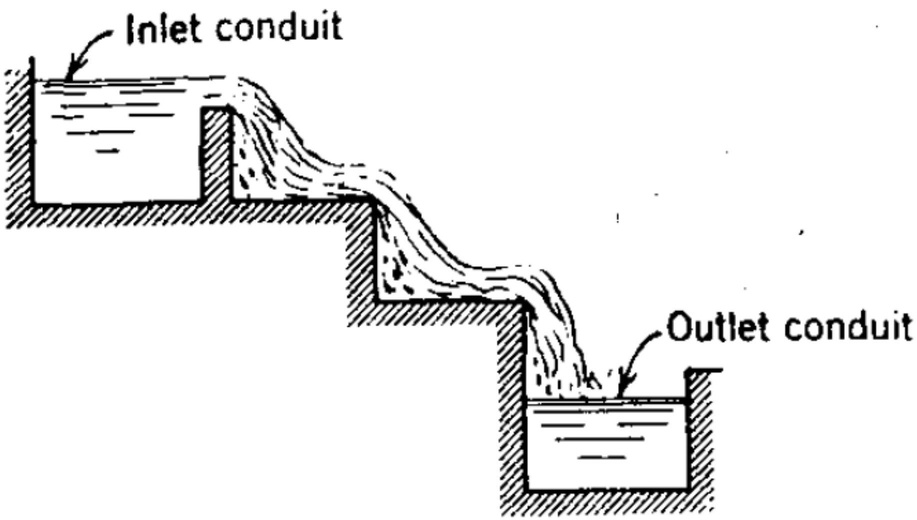








Design of cascade-type gravity aerators



In a single descent through a height h, elapsed time is $\sqrt{2h/g}$

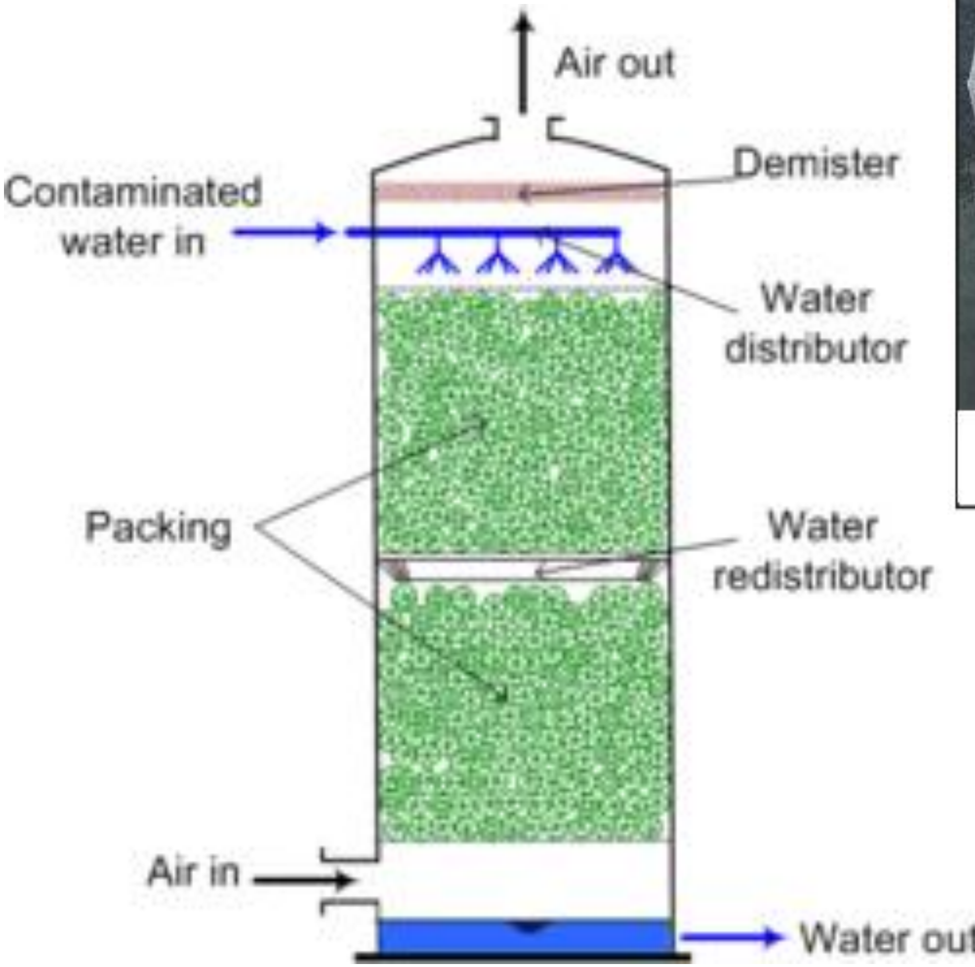
In n descents through the same vertical distance, elapsed time is $\sqrt{2nh/g}$

Therefore, elapsed time is proportional to $\sqrt{n}$

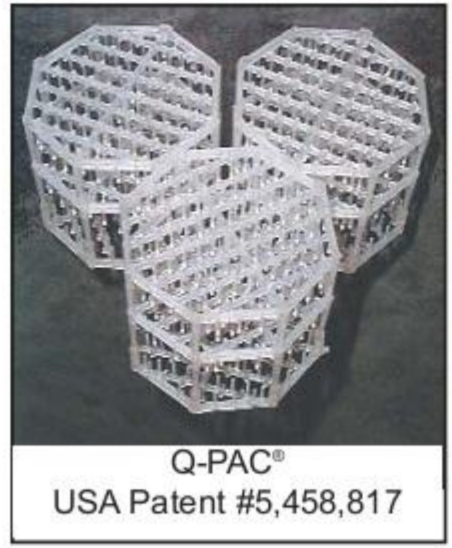
<u>Problem</u>:

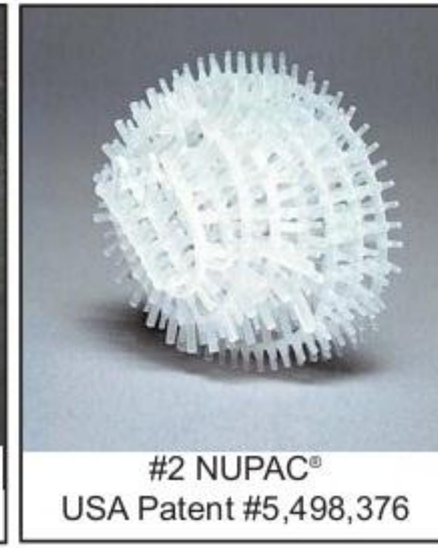
Find the time of exposure of water falling through a distance of 9 ft (a) in single descent, (b) in four descents

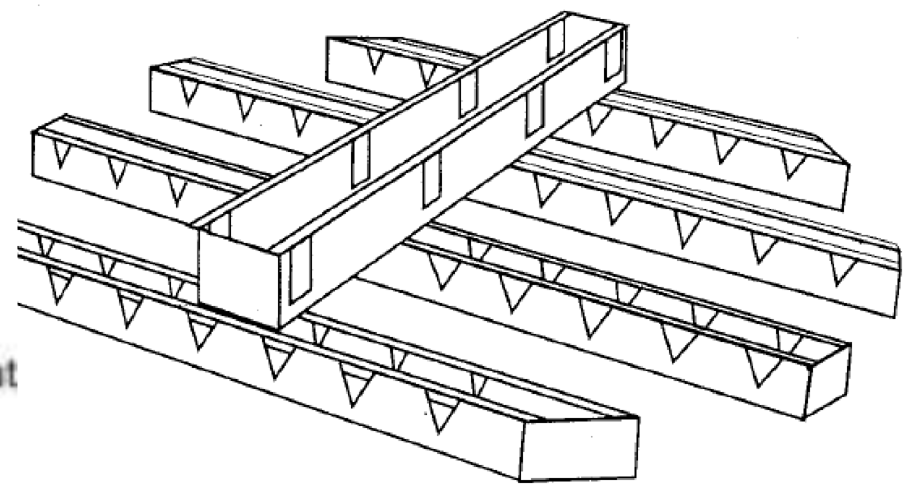
Packed Columns (gravity aerator)



Purewateroccasional.net







Trough - type distributor

Design of packed columns

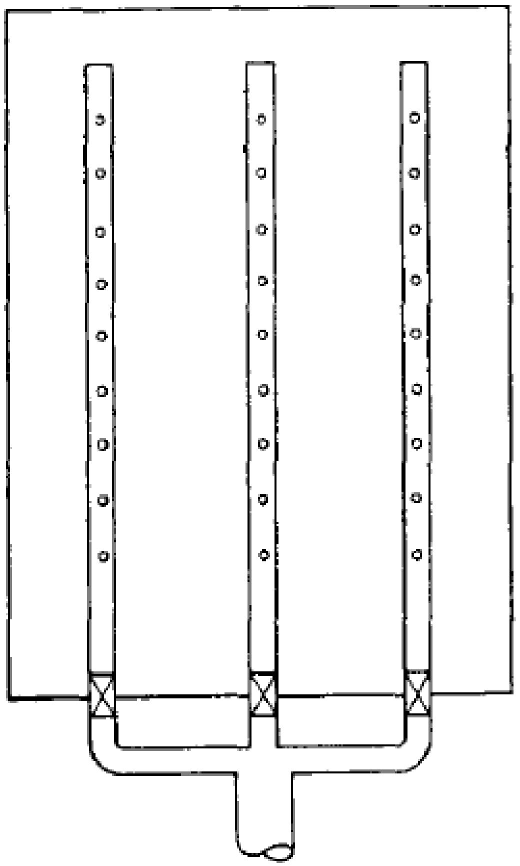
Height of packing column (in feet):

$$Z = \frac{Height\ of\ transfer\ unit\ (HTU)}{No.of\ transfer\ units\ (NTU)}$$

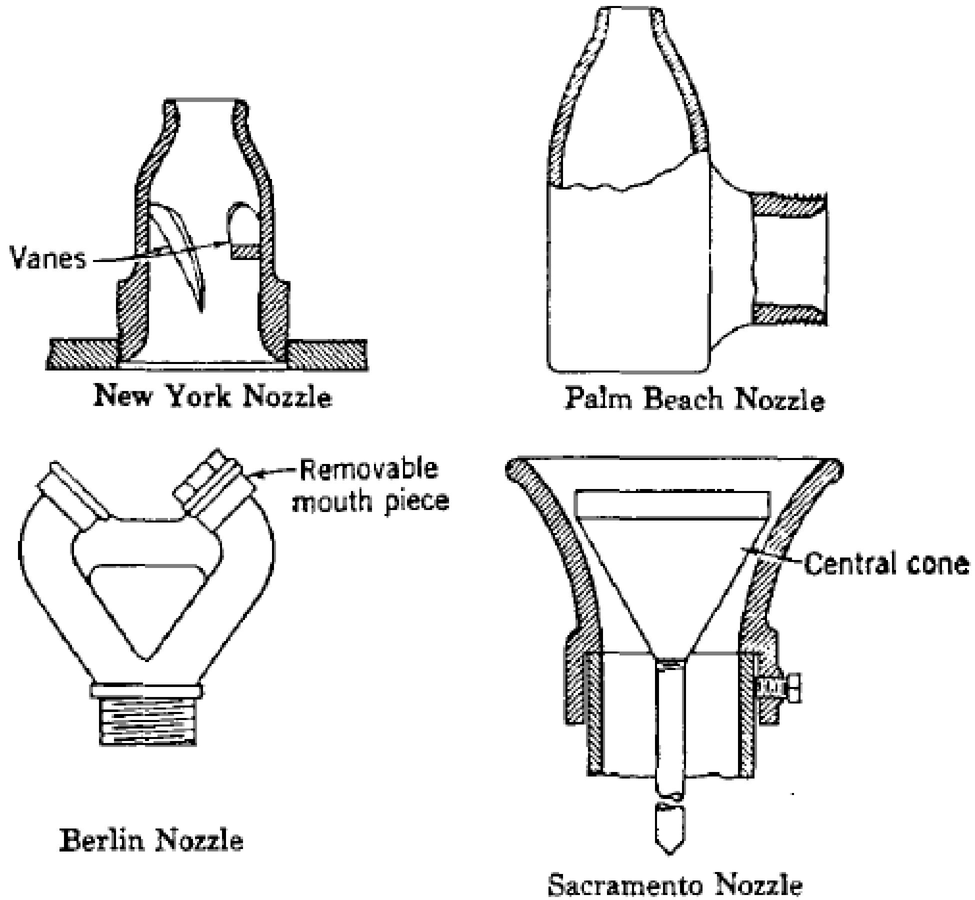
$$HTU = \frac{L}{K_L a C_0} \qquad NTU = \frac{R}{R-1} ln \frac{\left(\frac{X_i}{X_0}\right)(R-1)+1}{R}$$

X_i/X_0 = Ratio of influent to effluent liquid phase concentration
C_0 = molar density of water, lb mole/ft^2
R = Dimensionless stripping factor = $\frac{HG}{P_i L}$
L = Liquid flow, lb mole/hr/ft^2
G = Gas flow, lb mole/hr/ft^2
P_i = ambient pressure

Spray aerators



Nozzled aerator



Aerator nozzles

Design considerations for Spray aerators

Removal efficiency depends on the drop size, contact time (t) which also depends on the exit velocity (V) from the nozzle and the trajectory.

$$(C_t - C_0) = (C_S - C_0)[1 - exp(-K_L at)]$$

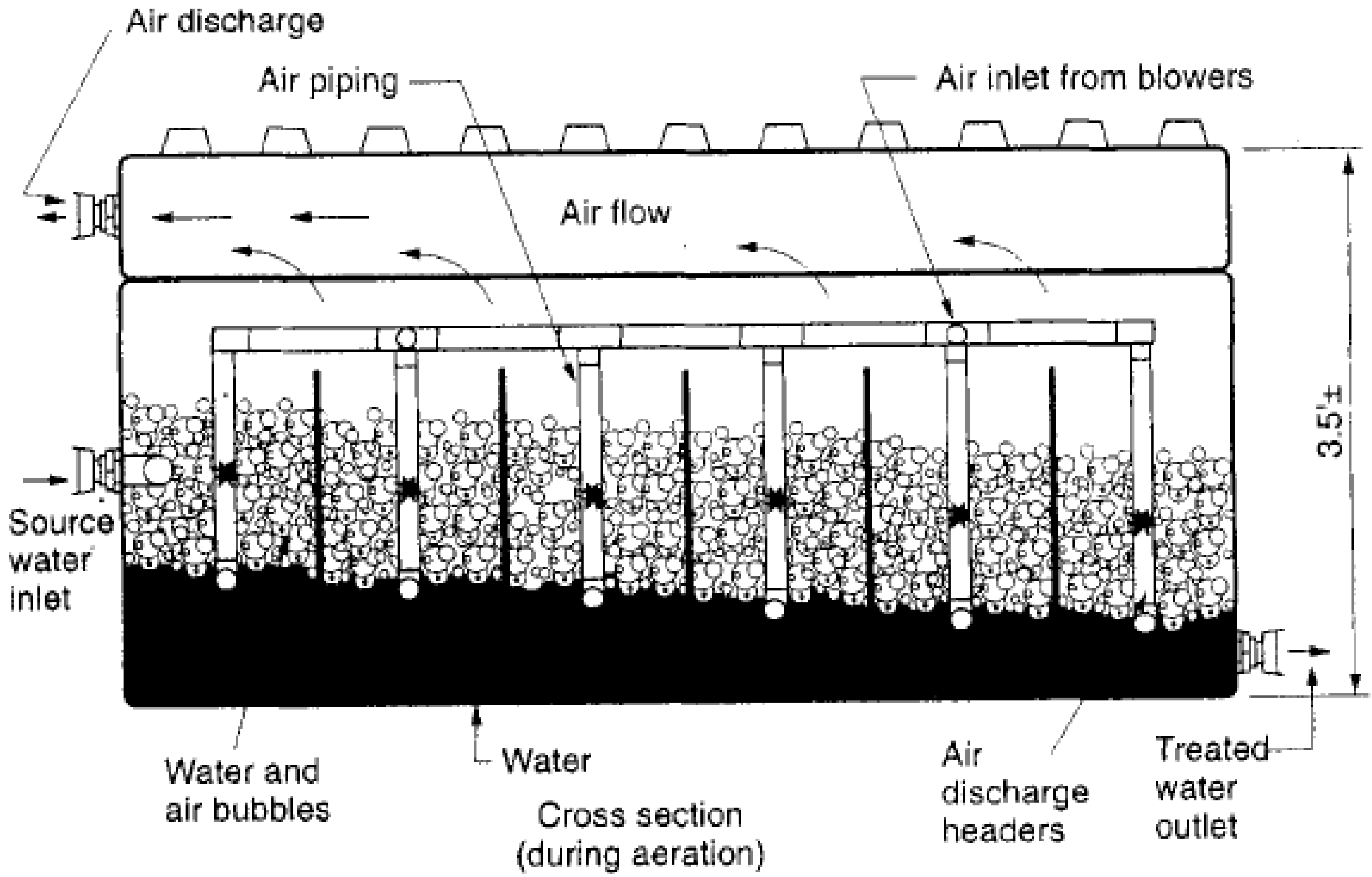
$$a = 6/d$$

$$t = (2V sin\alpha)/g$$

$$V = C_v\sqrt{2gh}$$

Cv = Coefficient of velocity of the nozzle
(0.4 – 0.95, from manufacturer)
α = angle of spray from the horizontal
d = mean diameter of the drop
(from manufacturer)

Air Diffusers



(Source: Lowry Engineering, Inc.)

Week-(17)

MD Ehasan Kabir

Nitrate Removal

Nitrate Removal techniques

Biological Denitrification

Reverse Osmosis

Ion Exchange

Removal techniques

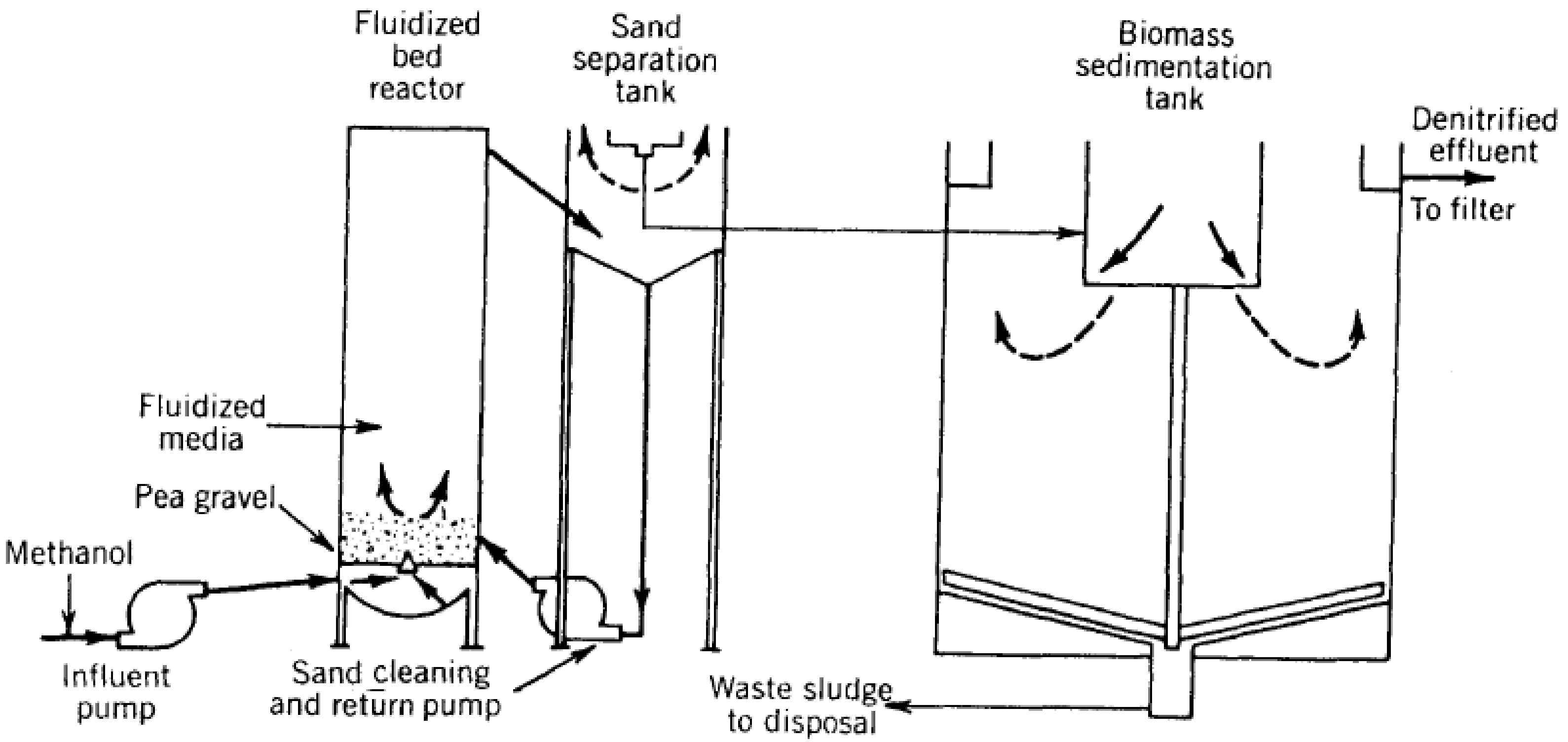
- ❑ Chemical coagulation
- ❑ Lime Softening
- ❑ Chemical reduction
- ❑ Biological denitrification
- ❑ Ion Exchange
- ❑ Reverse Osmosis

Not effective because of high solubility of nitrate

Certain drawbacks limit practicality (Cu and Fe^{2+} requirement, low removal percentage)

Feasible options

Biological Denitrification



Involves addition of **denitrifying bacteria** and **organic matter** in the flow stream.

Limitations:

(a) aeration to remove N_2 (b) Increased disinfection to remove bacteria and associated problems (e.g. THMs)

Reverse Osmosis

TABLE 15-1. Typical Performance of RO for Nitrate Removal[a]

Constituents	Pretreated Feed (mg/L)	Product (mg/L)	Brine (mg/L)
Calcium (Ca)	154	7.0	590
Magnesium (Mg)	3.8	0.17	15
Sodium (Na)	92	11	345
Potassium (K)	3.6	0.5	12.8
Carbonate (CO_3)	0.0	0.0	0.0
Bicarbonate (HCO_3)	7.8	5.2	45.9
Chloride (Cl)	92.8	6.0	346.9
Sulfate (SO_4)	380	5	1,500
Nitrate (NO_3)	93.0	31.9	270.2
Fluoride (F)	0.06	0.03	0.13
Iron (Fe)	<0.05	<0.05	0.08
Manganese (Mn)	<0.01	<0.01	0.01
Arsenic (As)	<0.01	<0.01	<0.01
Copper (Cu)	<0.01	<0.01	<0.02
Zinc (Zn)	0.01	0.007	0.02
MBAS	<0.1	<0.1	0.2
Hardness as $CaCO_3$	401.0	18.2	1,538
Total solids at 105°C	823	64	3,120
pH	5.2	5.6	5.9
Electrical conductivity mhos/cm ($K \times 10^6$) at 25°C	890	120	3,800

Nitrate Removal very low compared to other anions

RO may be used as a pretreatment for Ion exchange because it removes a large percentage of sulfate

Ion Exchage

- The only economical method to remove nitrate on a full scale
- Will be removed by **strongly basic anion exchange resins**.
- Nitrate removal will depend on
    - Sulfate concentration
    - TDS
    - Nitrate concentration
    - Total removal capacity of the resin

Membrane Processes in water treatment

Reverse Osmosis: principles, theory and applications

Membrane types and configurations, fouling of membranes

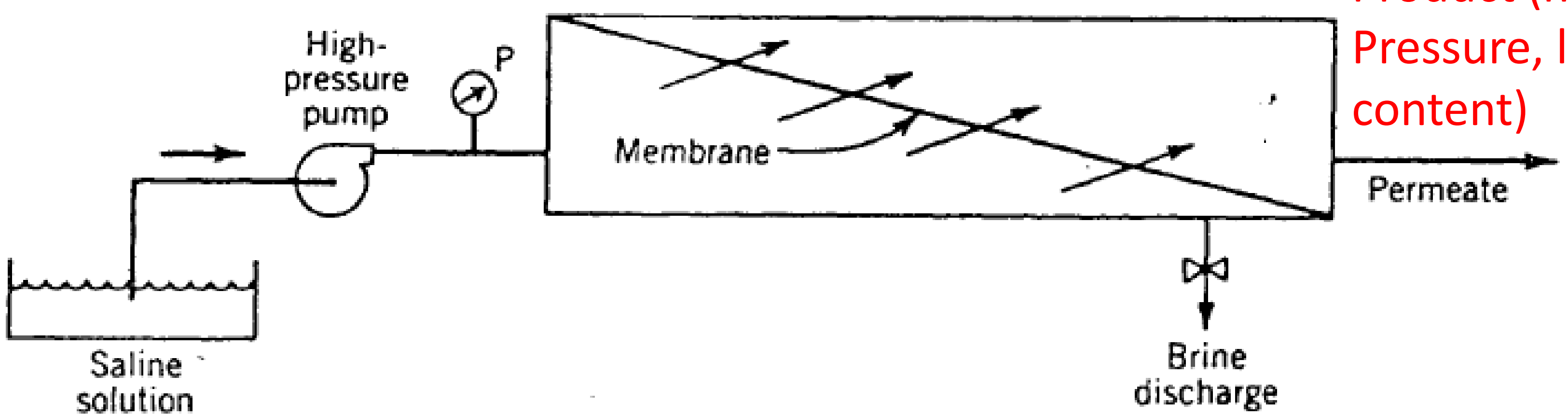
Factors affecting Reverse Osmosis

Electrodialysis: principles and applications

Elements of a typical ED system

What is "Reverse" Osmosis?

A membrane process for desalination by the application of hydrostatic pressure to drive the feedwater through a semipermeable membrane while major portion of its impurities are left behind



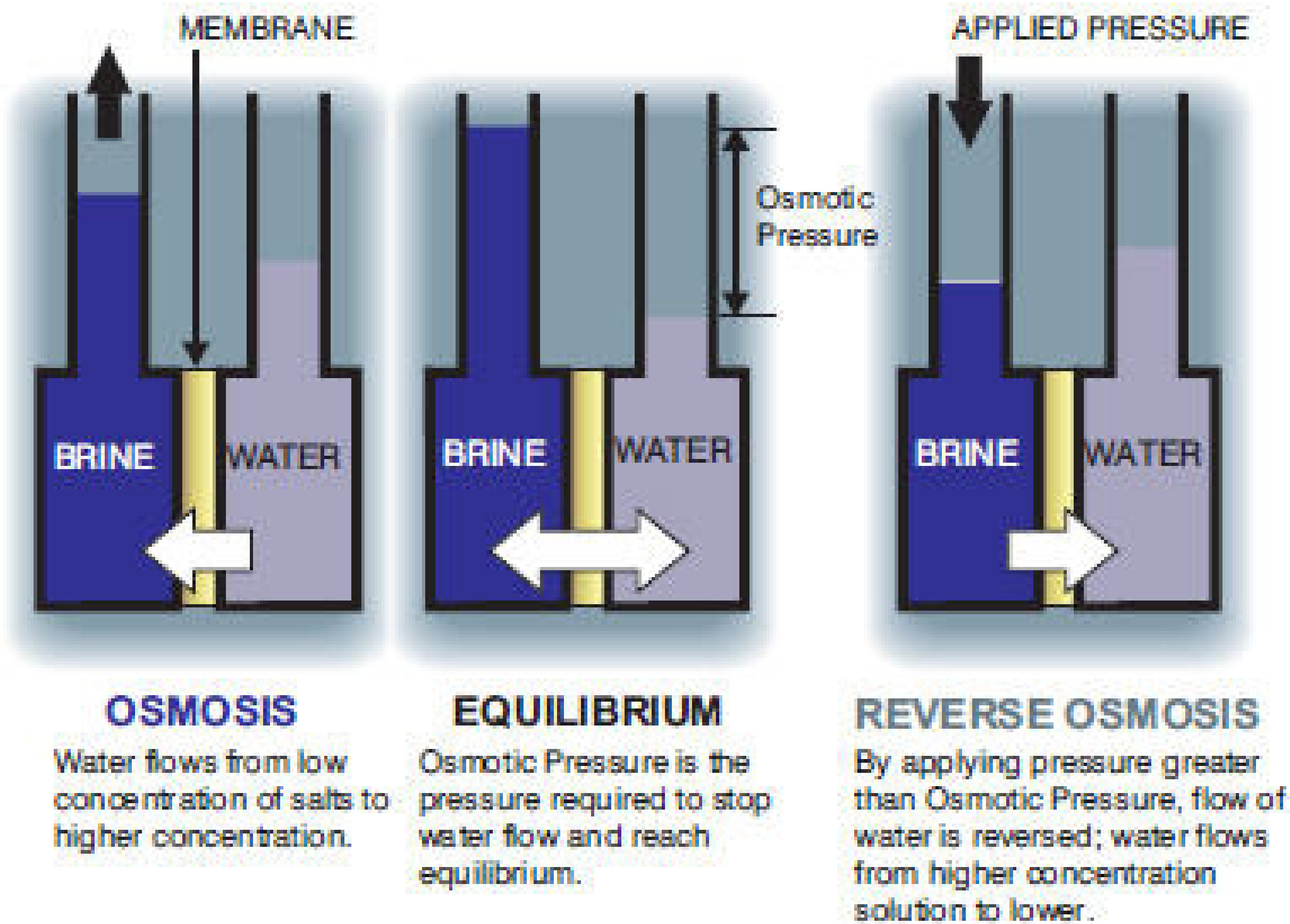
Product (near atm. Pressure, low salt content)

Waste (high pressure, high salt content)

Operating pressure: 300 – 400 psi (desalting brackish water)

800 – 1000 psi (seawater desalination)

Principles of Reverse Osmosis



Source: www.peerlesswater.com

Water and Salt fluxes

<u>Liquid flux:</u> $$F_w = K(\Delta P - \Delta\pi)$$

<u>Salt flux:</u> $$F_s = K(C_b - C_p)$$

ΔP = drop in total water pressure across the membrane
$\Delta\pi$ = drop in total osmotic pressure across the membrane
C_b, C_p = Salt concentrations on two sides of the membrane
K, k = empirical constants which depend on membrane structure, its method of manufacture and salt type

If feedwater pressure is <u>increased</u> keeping the solute concentration constant, the permeate quality is <u>increased</u>.

If feedwater solute concentration is <u>increased</u> at constant pressure, the permeate quality is <u>decreased</u>.

Water Recovery and Salt Rejection

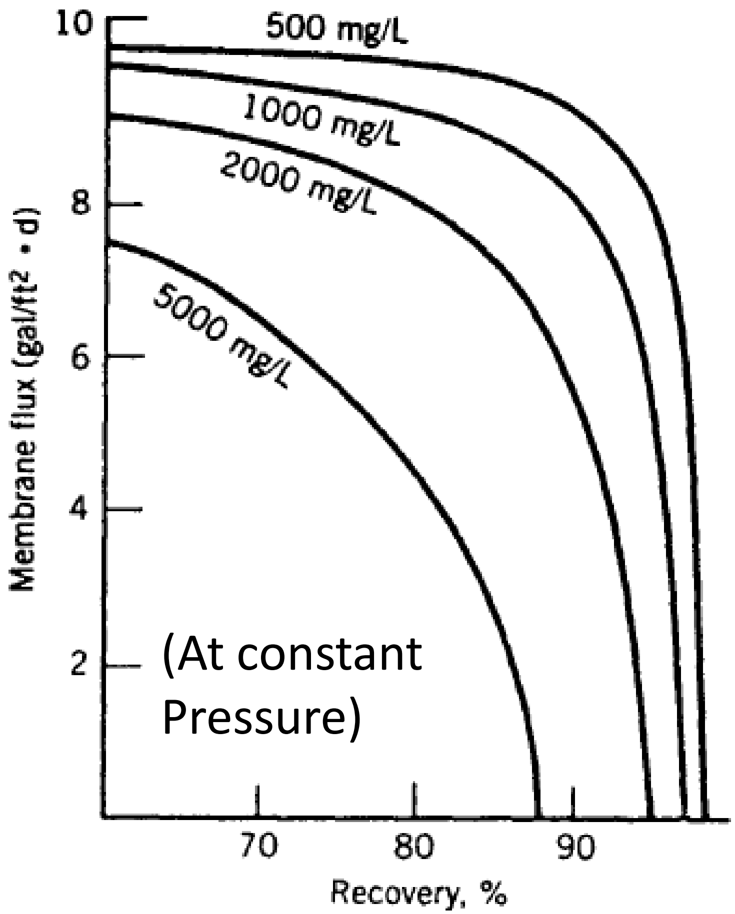
Water recovery is the percentage of feedwater recovered as product water.

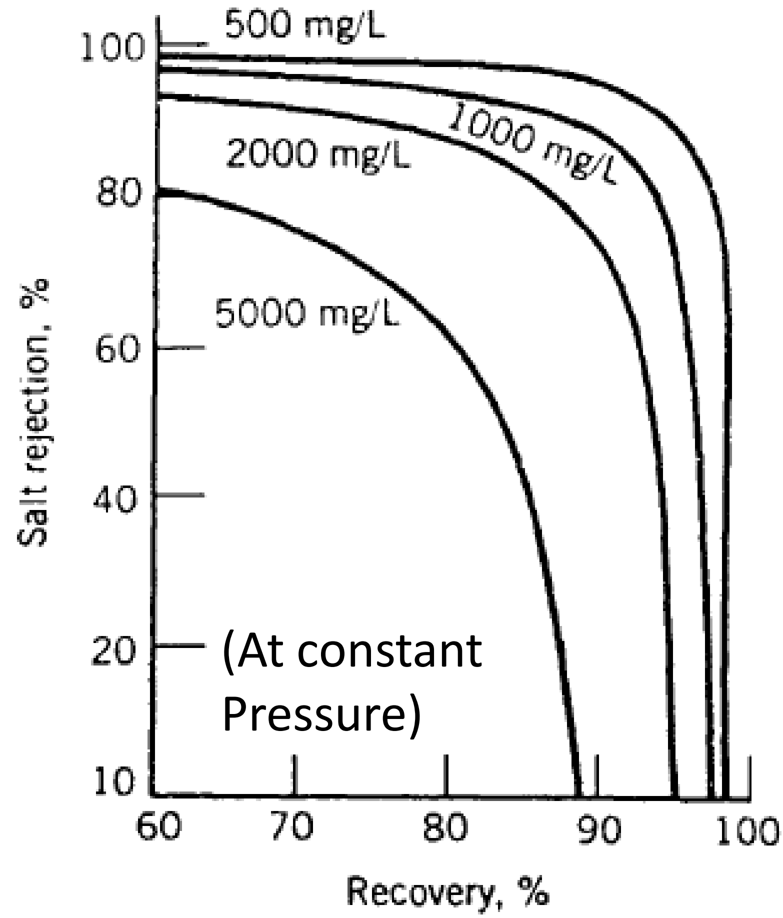
$$\text{Recovery} = \frac{product \quad water \quad flow}{feedwater \quad flow} \times 100\%$$

Salt rejection is a measure of the overall amount of salt rejected in the brine:

$$\text{Rejection} = \left(1 - \frac{product\ concentration}{feedwater\ concentration}\right) \times 100\%$$

Flux, rejection and recovery relationships





Osmotic Pressure

Osmotic pressure (psi) = $\pi = 1.12(T + 273)\sum m_i$

Temp (deg. C)

Summation of molalities of all ionic and nonionic constituents

TABLE 10-4. Typical Osmotic Pressures[a]

Compound	Concentration (mg/L)	Concentration (moles/L)	Osmotic Pressure (psi at 25°C)
NaCl	35,000	0.6	398
NaCl	1,000	0.0171	11.4
$NaHCO_3$	1,000	0.0119	12.8
Na_2SO_4	1,000	0.00705	6
$MgSO_4$	1,000	0.00831	3.6
$MgCl_2$	1,000	0.0105	9.7
$CaCl_2$	1,000	0.009	8.3
Sucrose	1,000	0.00292	1.05
Dextrose	1,000	0.00555	2.0

[a] A useful rule of thumb for estimating the osmotic pressure of a natural water is 1 psi/100 mg/L (ppm) of TDS.

SOURCE: Weber (1971).

Typical Applications of Reverse Osmosis

i. Desalination of brackish water (TDS < 10000 mg/L) to provide potable water

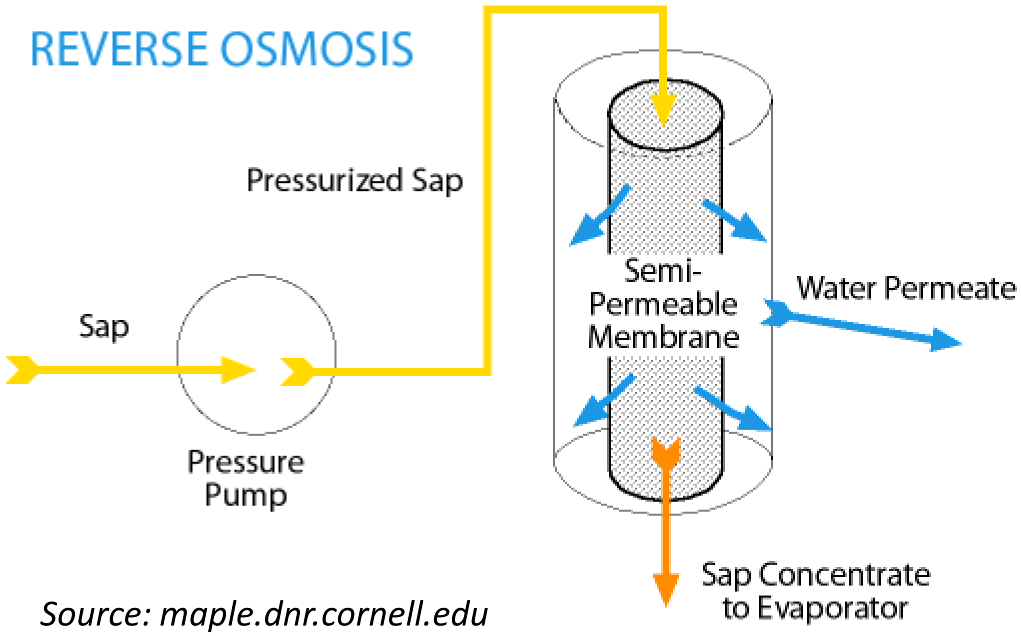
ii. Pretreatment of normal municipal water (TDS 500 – 1000 mg/L) preceding ion exchange deionization to make ultrapure water for applications such as boiler feed

iii. Recovery of valuable or reusable materials from a waste via the RO reject stream

iv. Reduction in the volume of waste, if required

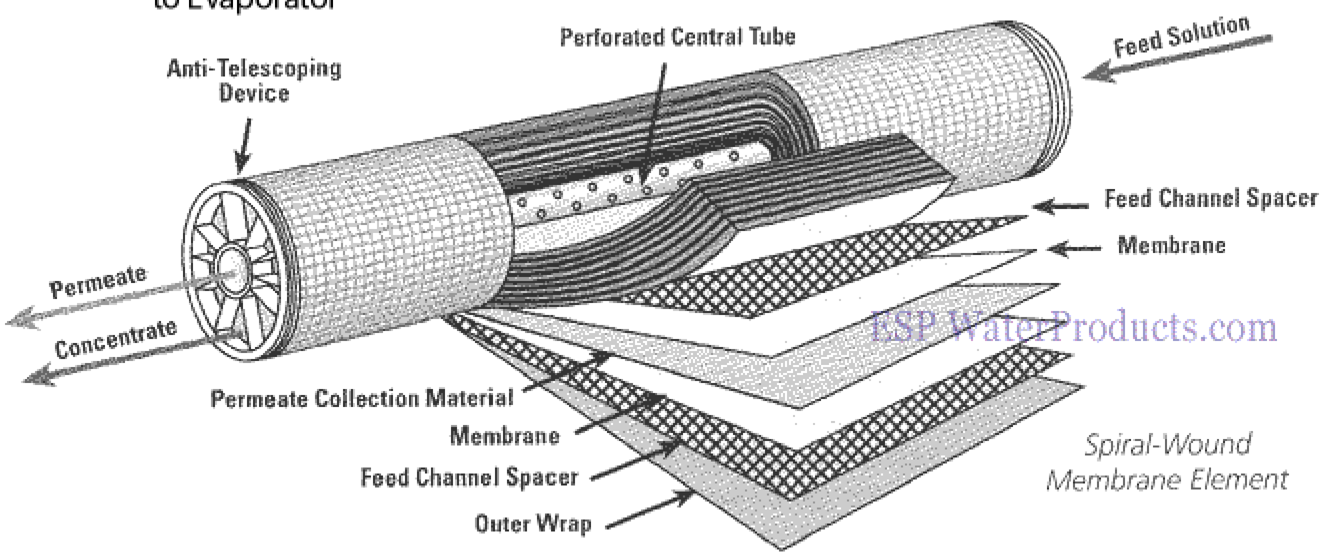
v. Water conservation or recovery such as the cooling tower blowdown

Membrane configurations



Source: maple.dnr.cornell.edu

- Spiral wound membrane
- Tubular membrane
- Hollow fine fibre module
- Plate and frame membrane



Large-scale setup

Source: pure-aqua.com

Type of membranes

Ideal Membrane properties

- Thin, imperfection-free
- Water can pass through with little hindrance
- Impermeable to ions
- Capable of withstanding pressure

Two types

Cellulose Acetate (CA)

- Cheaper, can tolerate Cl_2
- Subject to biological attack

Polyamide membranes

- Subject to degradation by Cl_2 or other oxidants
- not susceptible to biological attack
- Do not hydrolize. Best within pH 4-11
- Longer life (3-5 years)

Factors affecting Reverse Osmosis

1. Type of membrane 2. Molar concentration 3. Feed temp and pH
4. Feedwater pressure 5.Solute rejection

1. **<u>Type of membrane:</u>**

- Acetyl content↑, salt rejection ↑ and F_w↓
- Cellulose triacetate/ blended diacetate-triacetate membranes are more resistant to microbiological attack, greater hydrolytic stability, less compaction and productivity loss

2. **<u>Molar Concentration:</u>**

Osmotic pressure is proportional to molar concentration at any temperature

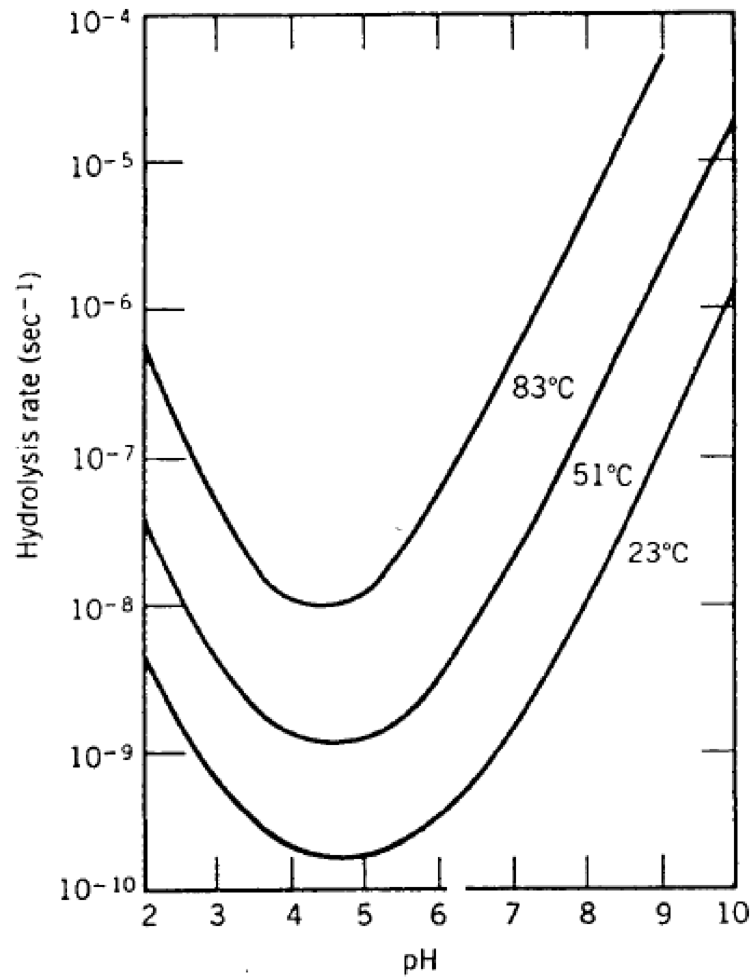
(see Table 10.4)

Factors affecting Reverse Osmosis

1. Type of membrane 2. Molar concentration 3. Feed temp and pH
4. Feedwater pressure 5.Solute rejection

3. <u>Feed temperature and pH:</u>

- o Fw increases 3% per deg.C increase in feedwater temp, Fs does not change significantly
- o Temp ↑, hydrolysis rate ↑
- o Optimum pH 5 – 6
- o Beyond the optimum range, hydrolysis rate ↑



Factors affecting Reverse Osmosis

1. Type of membrane 2. Molar concentration 3. Feed temp and pH
4. Feedwater pressure 5.Solute rejection

4. <u>Feedwater pressure:</u> High pressure feed is desirable

$$F_w = K\left(\Delta P - \Delta \pi\right) \qquad F_w \propto \left(\Delta P - \Delta \pi\right)$$

5. <u>Solute rejection:</u>

- Multivalent ion rejection > univalent ion rejection
- Undissociated/poorly dissociated rejection < dissociated ions
- Acid/base rejection < Salts of those acid/bases
- Co-ion rejection (Rejection of Na as Na_2SO_4 > as NaCl)
- Poor rejections for → low mol. Wt. organic acids
  → Trace quantities of univalent ions

Membrane Fouling and productivity

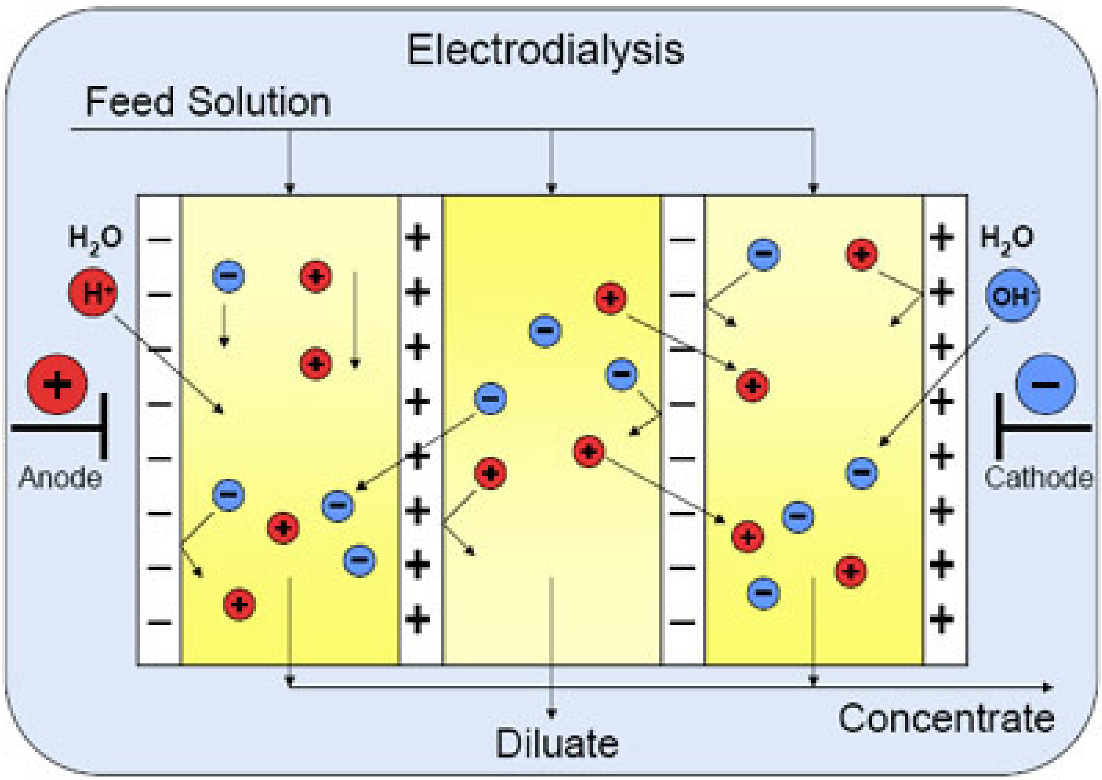
Lack of pretreatment of feedwater or adequate cleaning of membrane can cause membrane fouling and reduced water productivity

<u>Five types of fouling:</u>

1. Membrane scaling
2. Fouling by metal oxides
3. Plugging
4. Colloidal fouling
5. Biological fouling

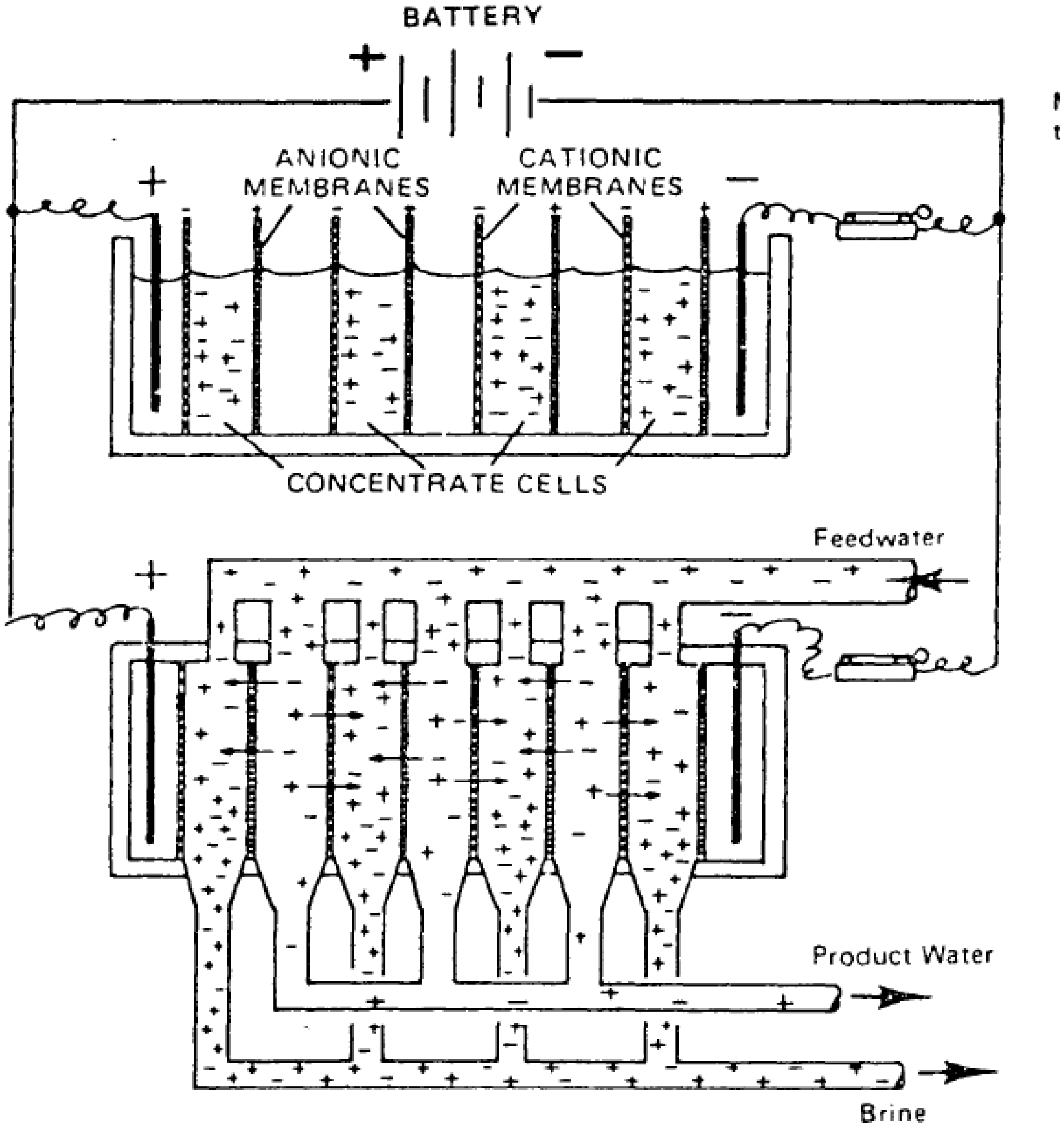
Electrodialysis

Electric energy is used to transfer ionized salts from feedwater through selective membranes, leaving behind purified product water



Source: fumatech.com

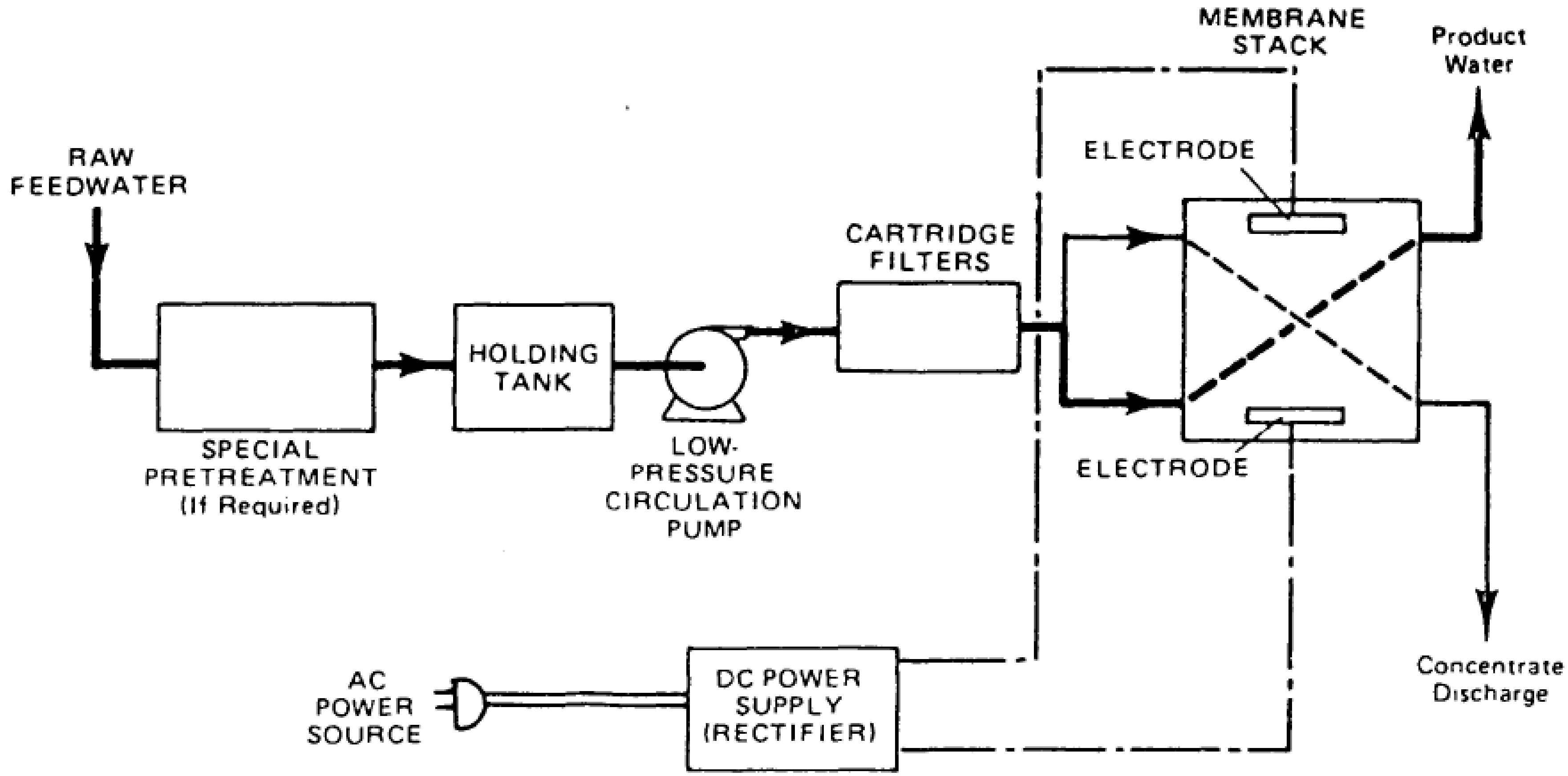
Electrodialysis



- Cation and anion-selective membranes placed alternatively to form a membrane stack.

- Concentrated and dilute/pure solutions collected from the spaces between alternating membranes.

Basic components of an ED unit



Three main elements: (1) Pressurized water supply system, (2) membrane stack and (3) DC power supply

Sedimentation

Sedimentation theory

Different types of settling mechanisms

Ideal sedimentation basin and departure from ideality

Sediment tank innovations

Factors affecting sedimentation

Sedimentation tank design criteria, case study

Floatation process

Sedimentation theory

For a discrete spherical particle, settling velocity/terminal velocity is obtained when

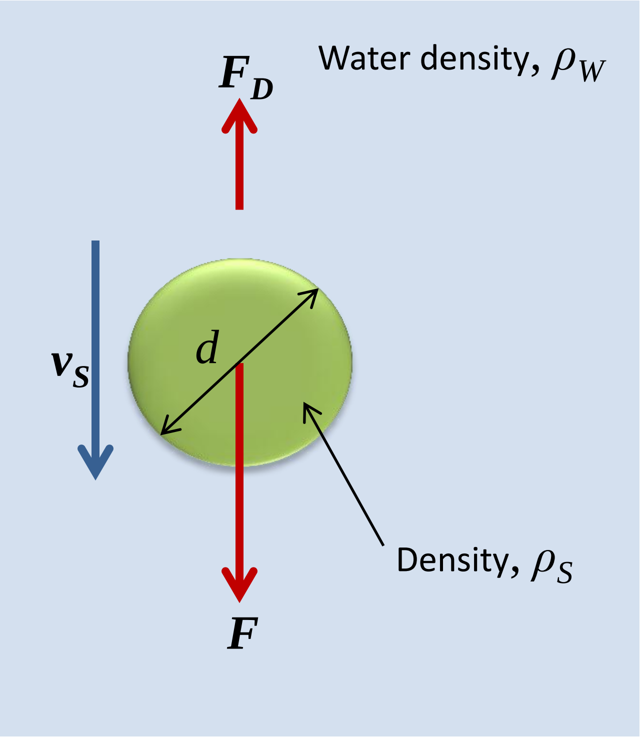
Gravitational force (F) = Frictional Drag force (F_D)

$$(\rho_S - \rho_W)gV = C_D A_C \rho_W v_S^2 / 2$$

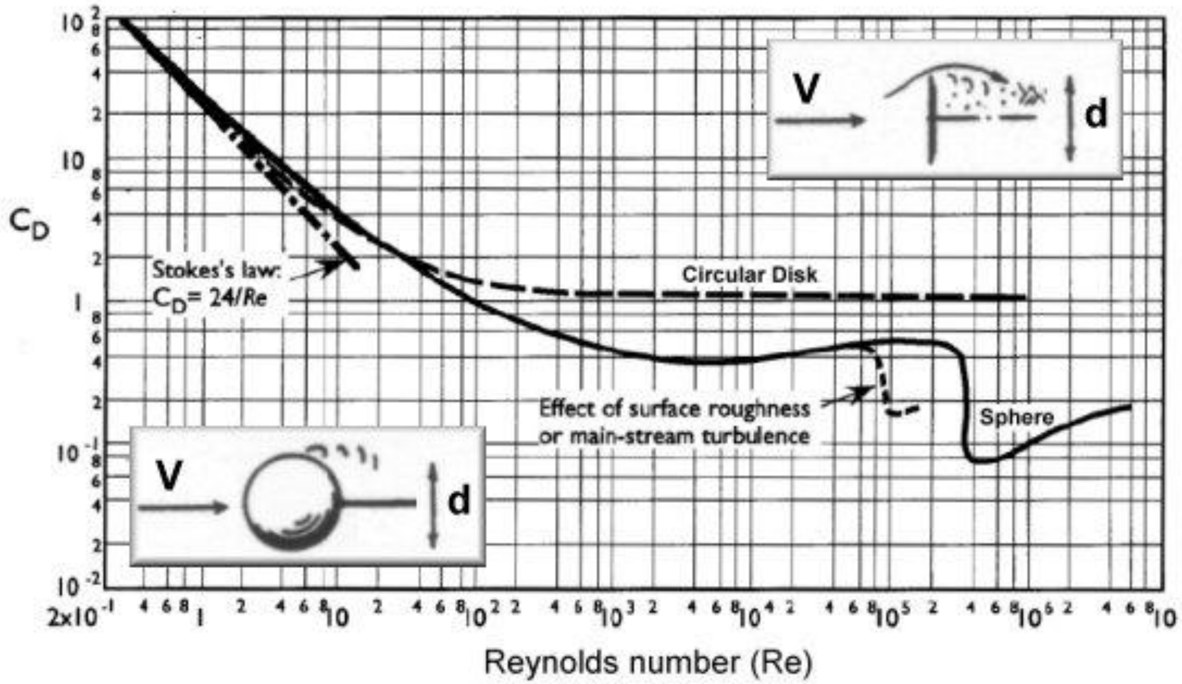
$$v_S = \sqrt{\frac{2gV(\rho_S - \rho_W)}{C_D \rho_W A_C}}$$

$$v_S = \sqrt{\frac{4g(\rho_S - \rho_W)d}{3C_D \rho_W}}$$

V = volume of particle = $\pi d^3/6$
A_C = X-sectional area of particle = $\pi d^2/4$
v_S = settling velocity
C_D = drag coefficient



Determination of Drag coefficient, C_D



$C_D = 24/R$ $\quad R \le 1$ → Typical Reynolds number for particles in water treatment

$C_D = 24/R + 3/R + 0.34 \qquad 1 < R < 10^4$

$C_D = 0.4 \qquad 10^4 < R < 10^5$

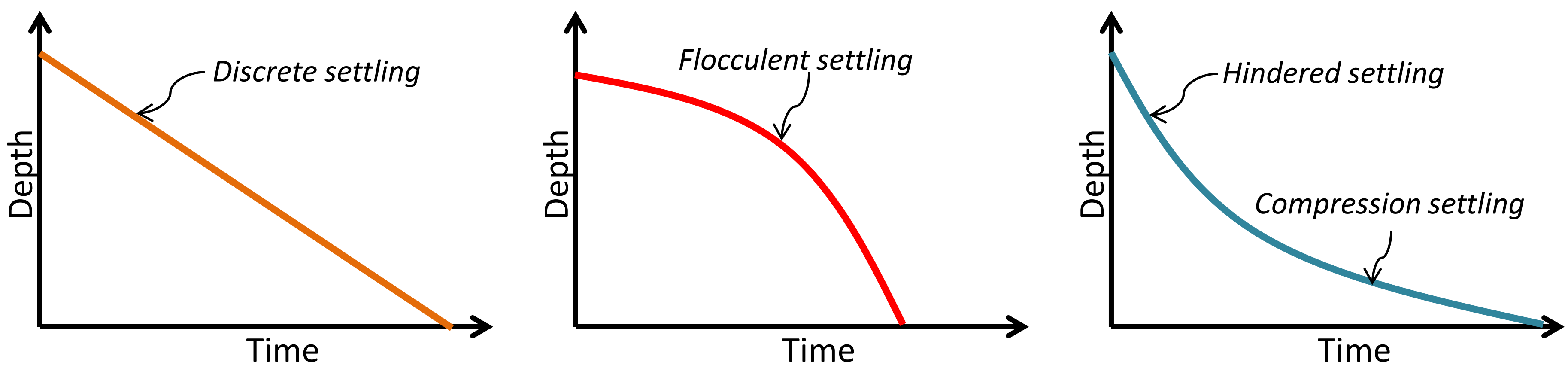
$$v_S = \frac{g(\rho_S - \rho_W)d^2}{18\mu}$$

Different settling types

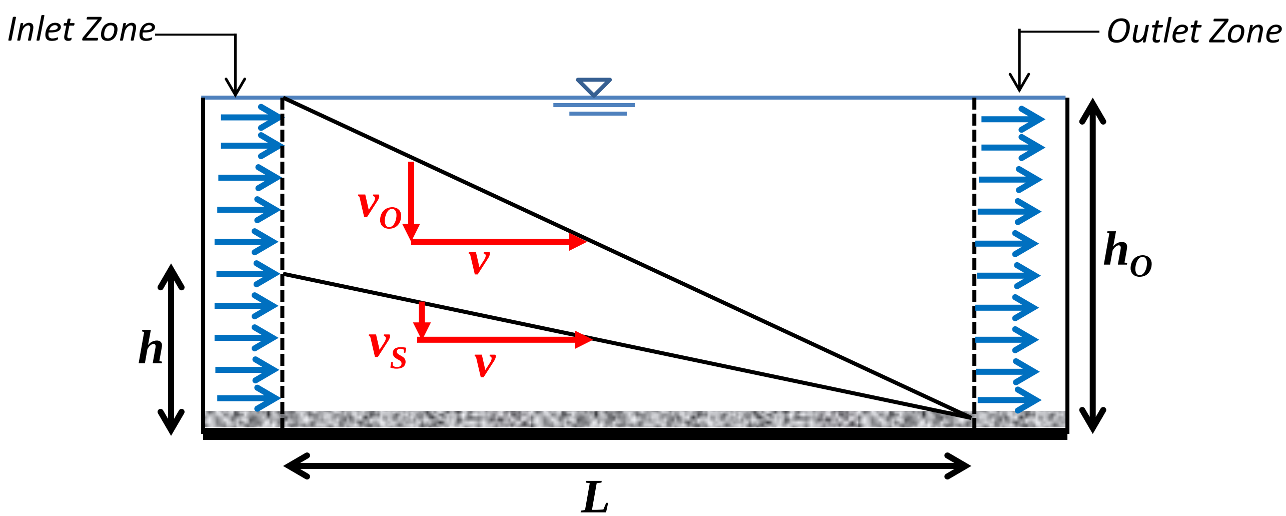
Type I: discrete settling

Type II: Flocculent settling

Type III: Zone settling (hindered and compression settling)



Ideal Sedimentation Basin



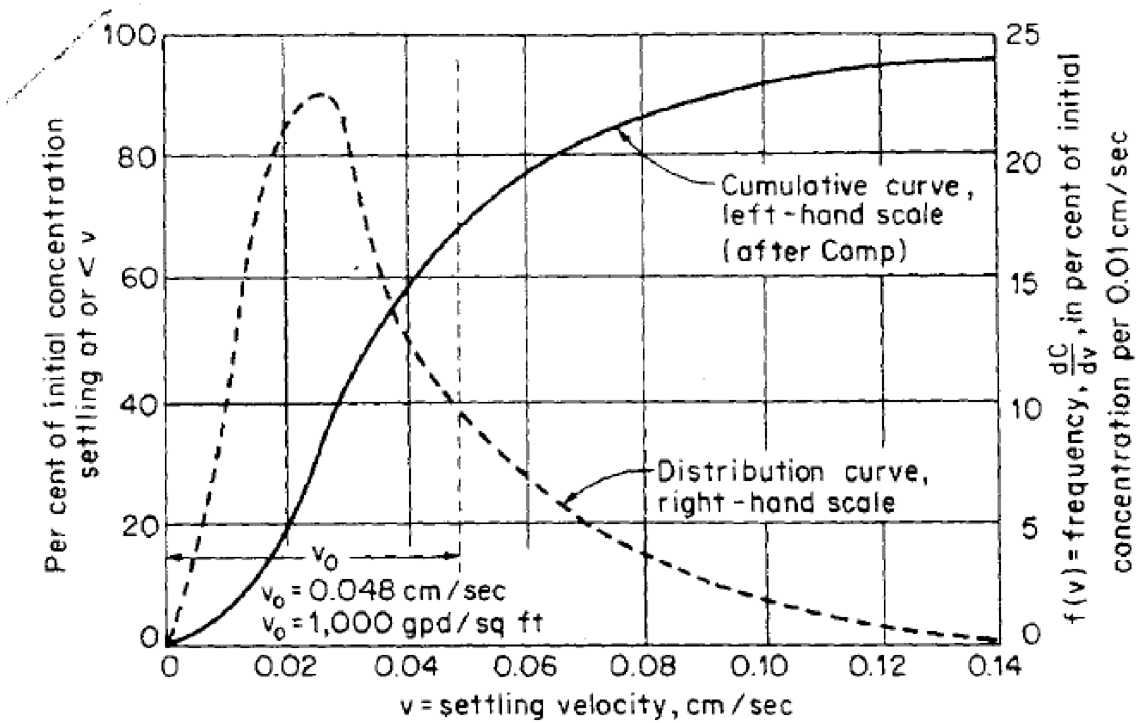
Overflow rate: $v_O = h_O / t_O = h_O Q / V = Q / A$

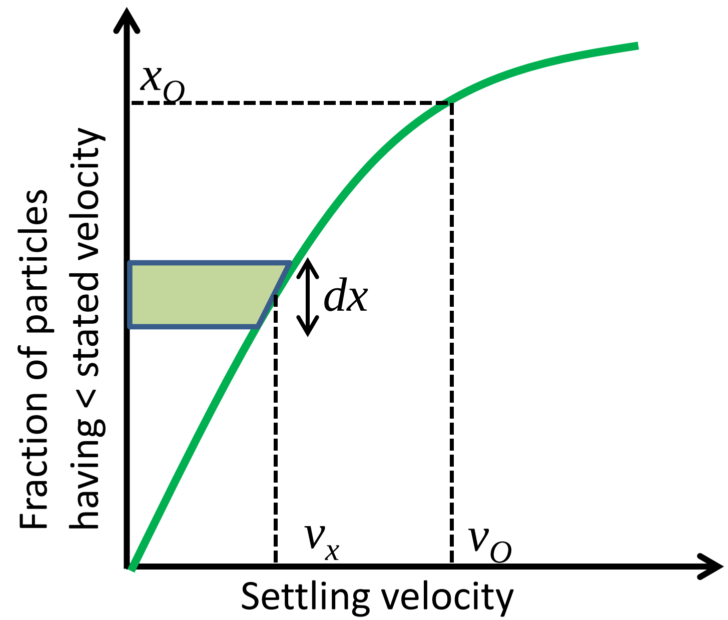
Overflow rate identifies the smallest settling velocity attributable to the class of particles which experience complete removal

For $v_S < v_O$, the removal percentatge will be $100(v_S/v_O)$ because

$$h / h_O = v_S / v_O$$

Removal efficiency from settling velocity characteristics





Total particle fraction that will be removed:

$$(1 - x_O) + \frac{1}{v_O}\int_0^{x_O} v_x\, dx$$

← Applicable only for ideal settling

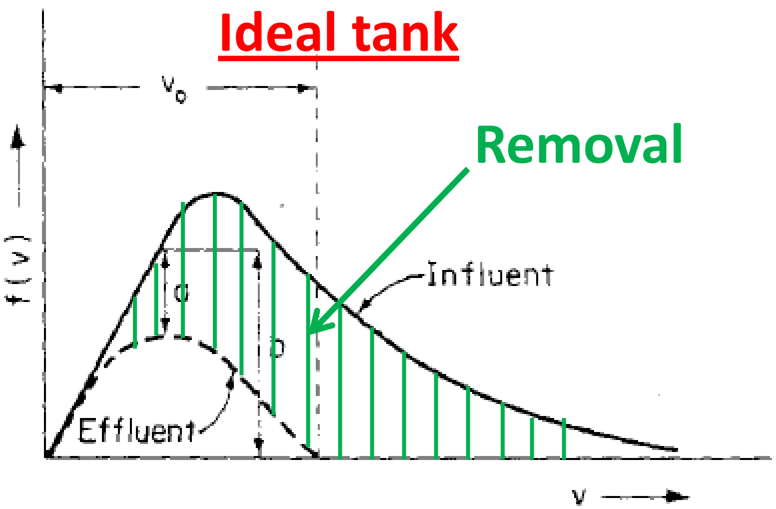
Problem: discrete settling

The settling characteristics of a suspension at 2 ft depth are as follows:

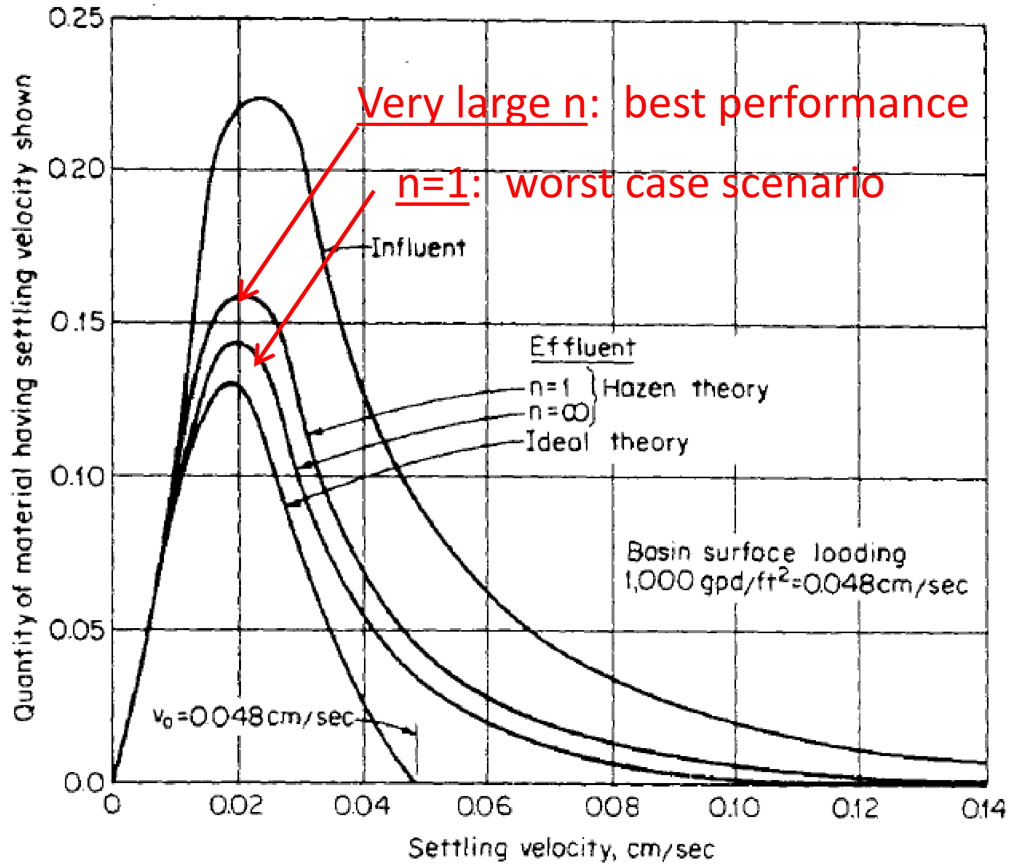
Time (min)	Suspended Solids (mg/l)
0	300
5	210
10	156
20	90
40	50
60	40

Compute the removal efficiency of the basin when Q = 1.5 cfs and A = 360 ft^2. Assume ideal settling.

Ideal settling and departure from ideality

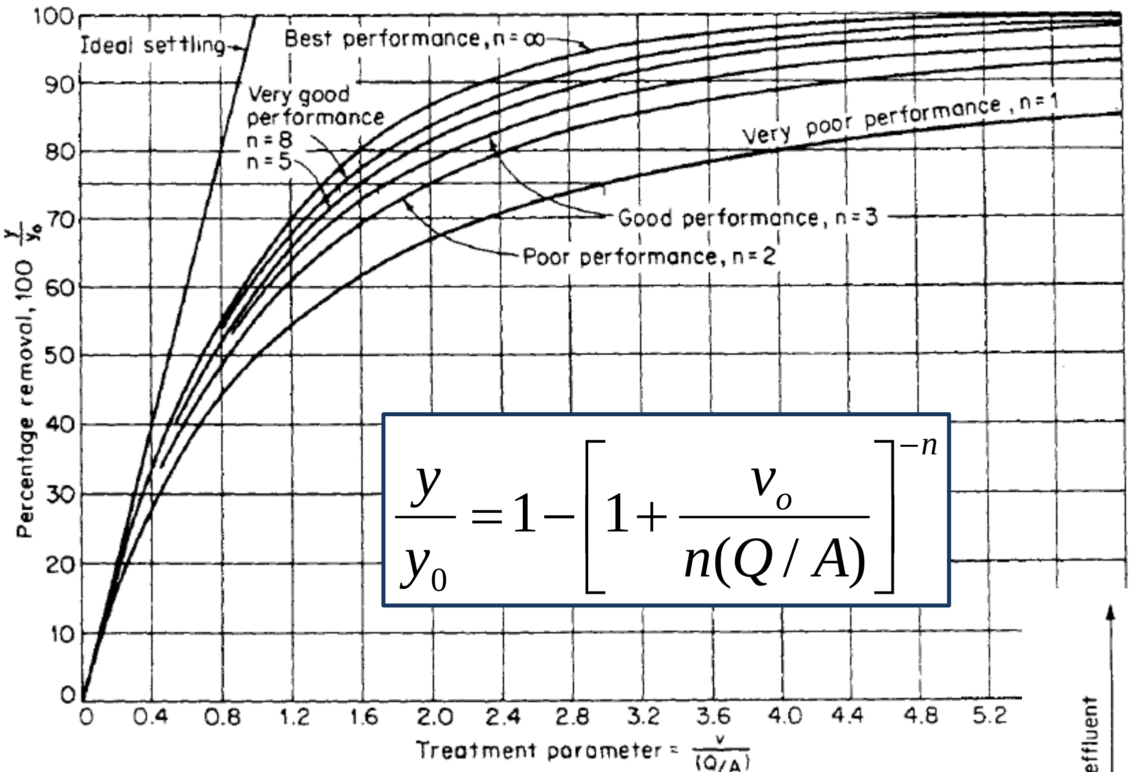


Reasons for departure: surface currents, convection currents, eddy currents



Hazen estimated the settling performance if a settling basin is subdivided into *n* number of hypothetical basins connected in series.

Removal efficiency in non-ideal cases



$$\frac{y}{y_0} = 1 - \left[1 + \frac{v_o}{n(Q/A)}\right]^{-n}$$

How to improve performance:

- Reducing the surface overflow rate
- Covers for the basins
- Baffle walls at the inlet and outlet
- Larger height of tank

Tracer tests are used to estimate *n*

$$n = \frac{t_{mean}}{t_{mean} - t_{\mathrm{mode}}}$$

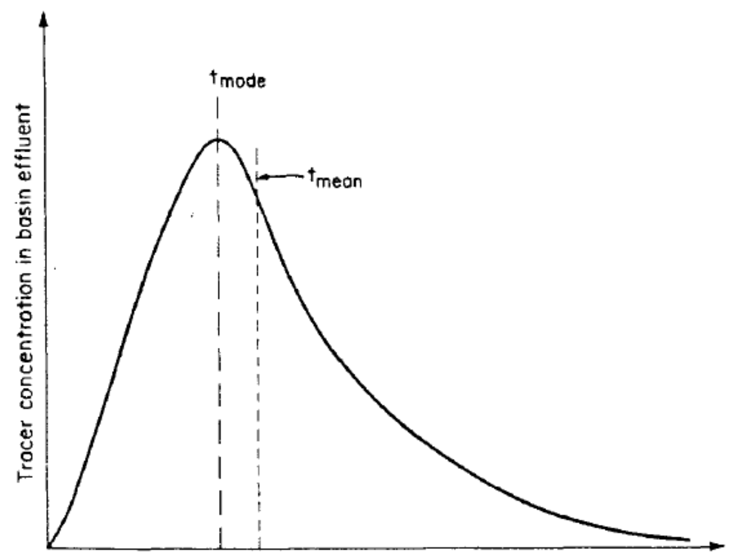
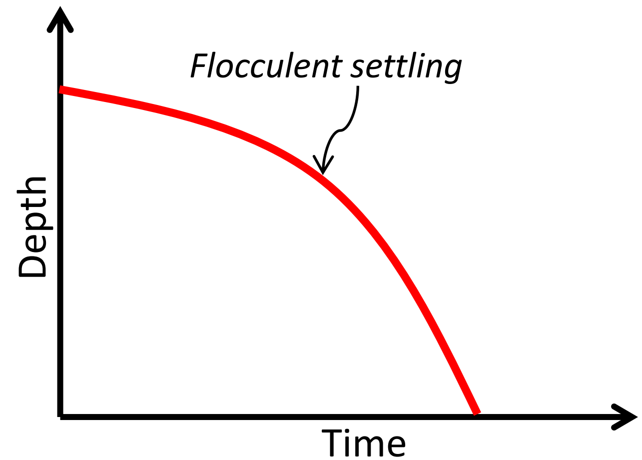


Fig. 14 Time after addition of tracer to basin influent.

Flocculent suspensions

Particles will agglomerate while settling, resulting in an increase in particle size.



The density variation of small flocs may be expressed by:

$$\rho_S - \rho = kd^{-0.7}$$

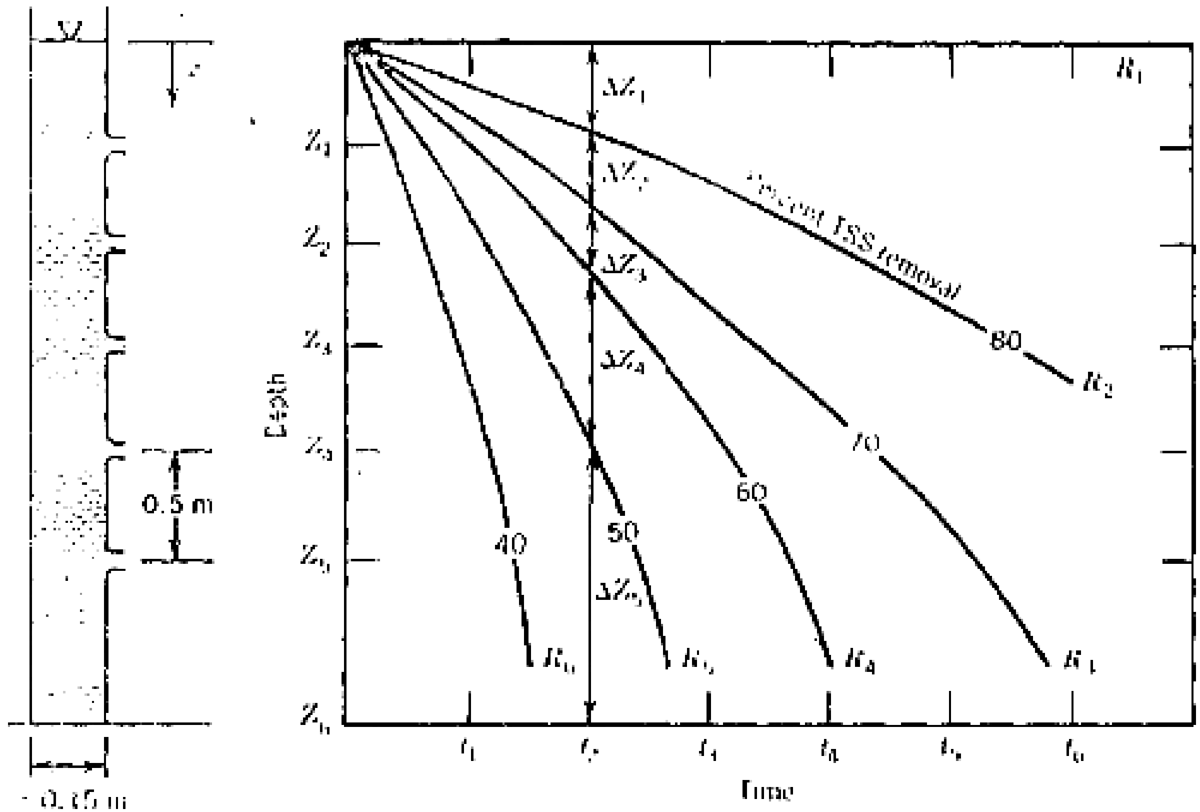
$$v_S = \frac{g(\rho_S - \rho)d^2}{18\mu}$$

ρ_S = density of the floc
ρ = density of water
d = the diameter of the particle
k = a coefficient dependent upon the characteristics of the water and the chemicals involved

Will cause an increase in settling velocity

Estimating removal efficiency for flocculent settling

Settling analyses are peformed in columns equal in depth to the proposed clarifier



<u>Total particle fraction that will be removed</u>:

$$X_r \cong \frac{\Delta Z_1}{Z_6}\left(\frac{R_1 + R_2}{2}\right) + \frac{\Delta Z_2}{Z_6}\left(\frac{R_2 + R_3}{2}\right) + \frac{\Delta Z_3}{Z_6}\left(\frac{R_3 + R_4}{2}\right) + \frac{\Delta Z_4}{Z_6}\left(\frac{R_4 + R_5}{2}\right)$$

Problem: Flocculent settling

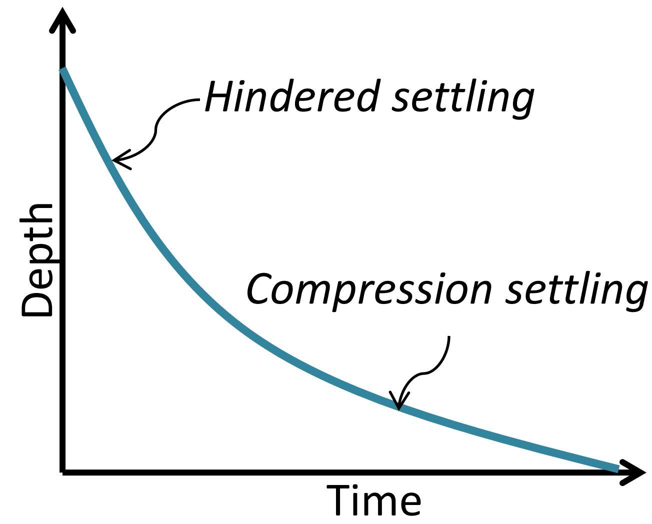
Suspended Solids at different time and depths are shown in the table. The initial SS concentration is 300 mg/L.

Time (min)	10	20	30	40	50	60
Depth (ft)						
1	204	150	126	96	75	60
2	213	180	150	129	99	81
3	216	189	165	144	120	99
4	219	195	171	156	135	105
5	225	210	177	165	144	120

Calculate the efficiency of flocculent settling basin of depth 5 ft when the detention time is (a) 40 min and (b) 30 min.

Zone settling

Individual particles are so close that the displacement of water by the settling of one affects the relative velocities of its neighbours.



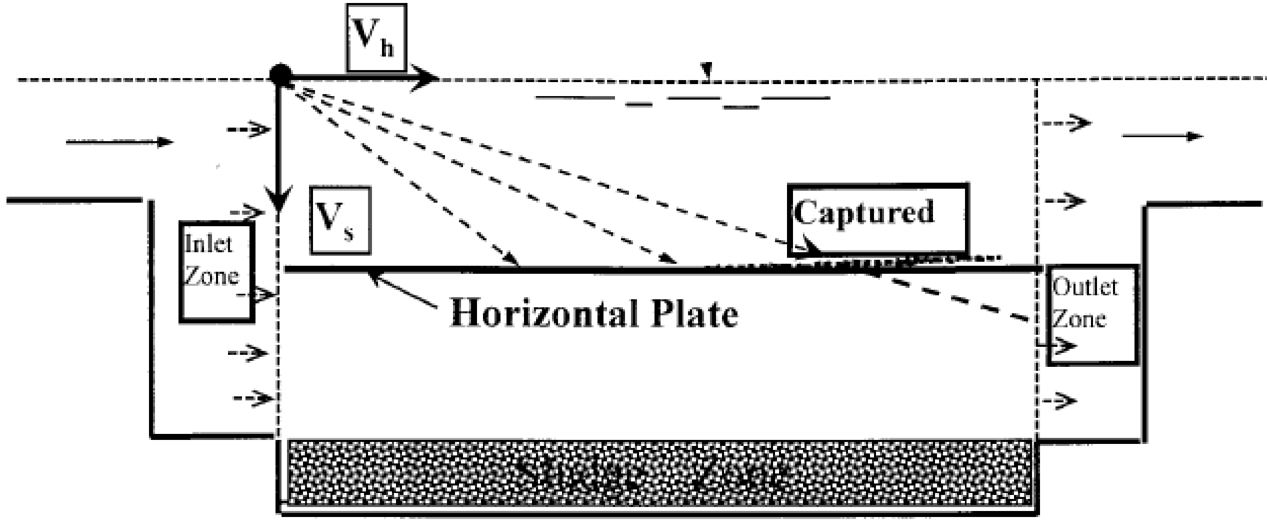
The hindered settling velocity:

$$v_h = v(1 - C_v)^{4.65}$$

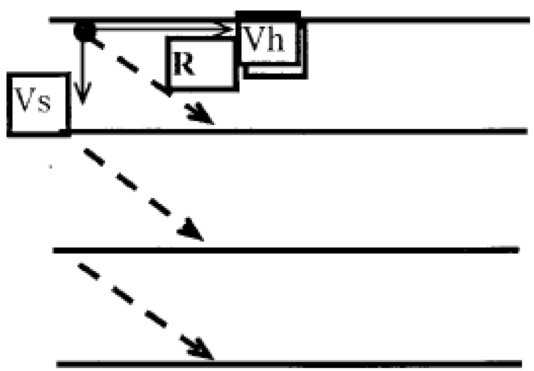
v = the free settling velocity
C_v = the volume of the particles divided by the total volume of the suspension

Typically does not happen in sedimentation tanks, but occurs in sludge thickeners and at the bottom of secondary clarifiers in biological treatment systems

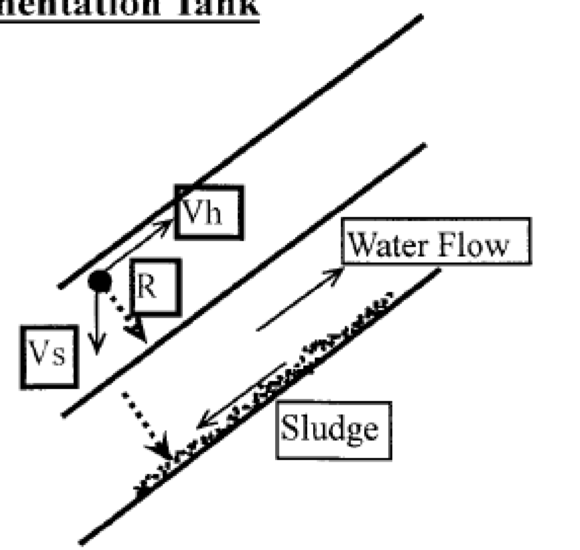
Sedimentation Basin Innovations



Two Storied Sedimentation Tank

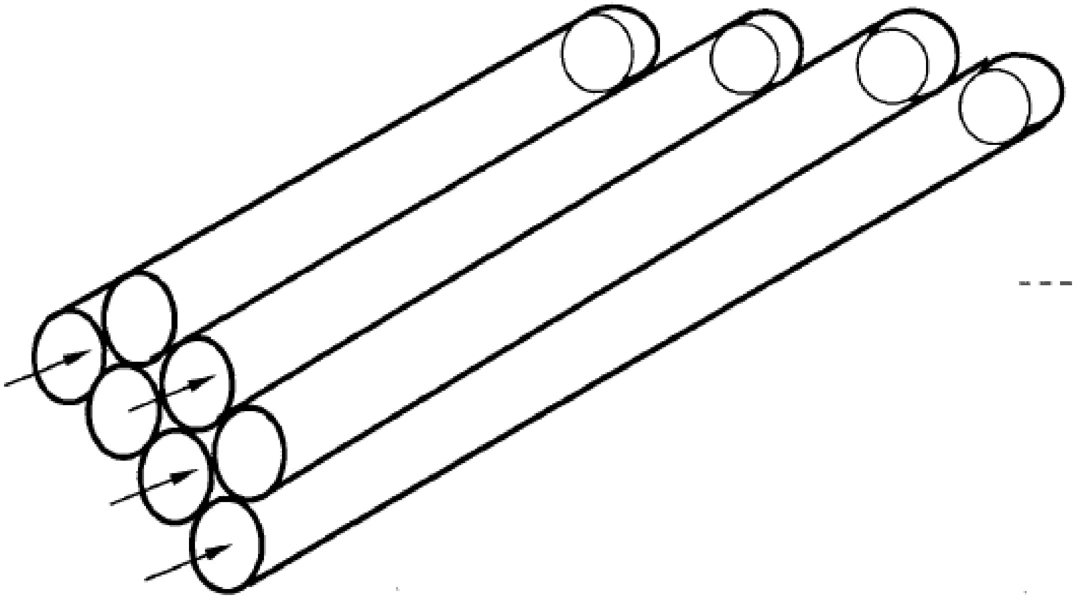


Horizontal Parallel Plates Separator

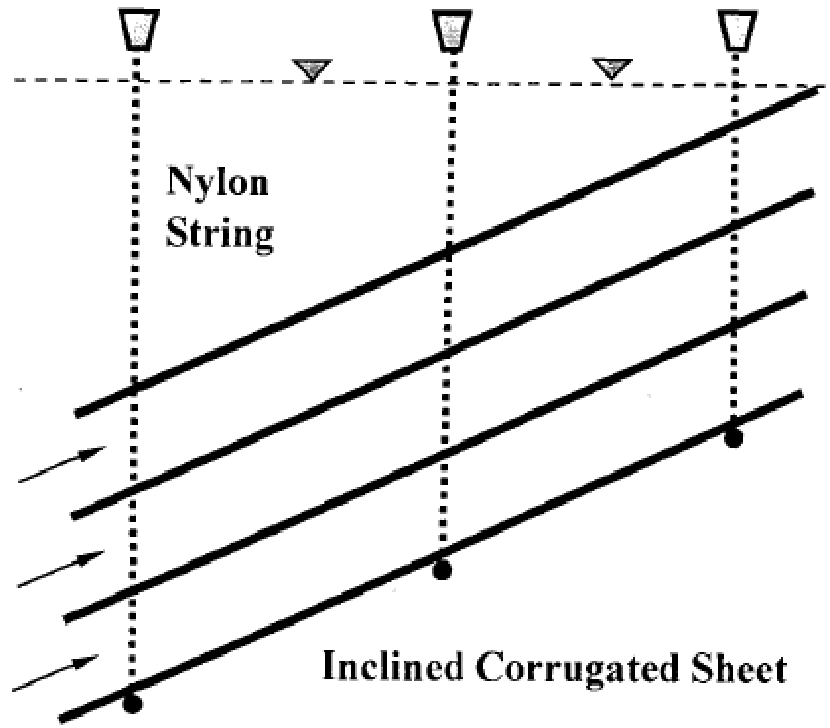


Inclined Parallel Plates Separator

Sedimentation Basin Innovations

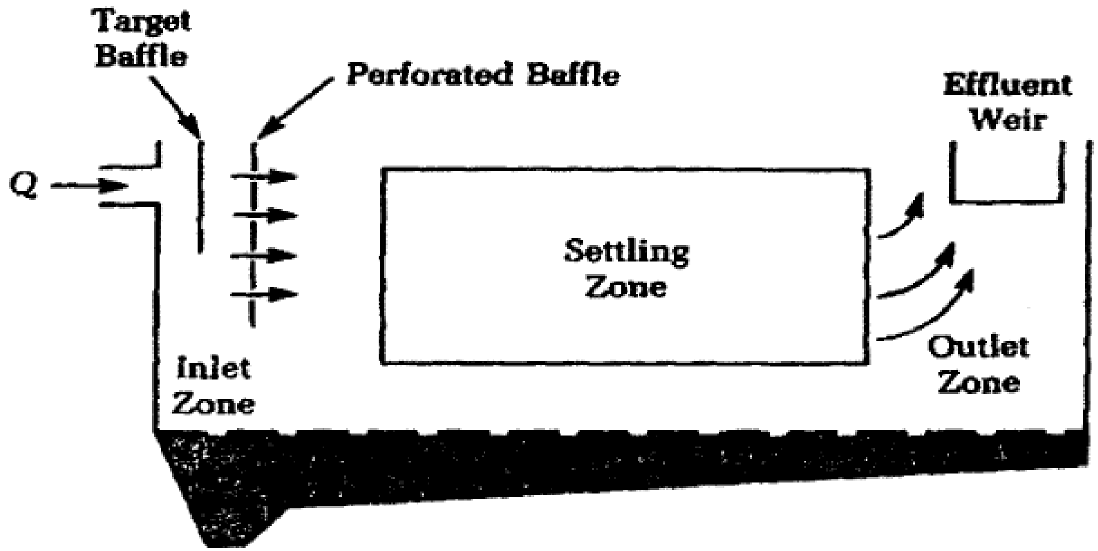


PVC Bunch of Pipes
Tube Settler



Increases the plan area (A) for the same flowrate (Q) and reduces the effective SOR

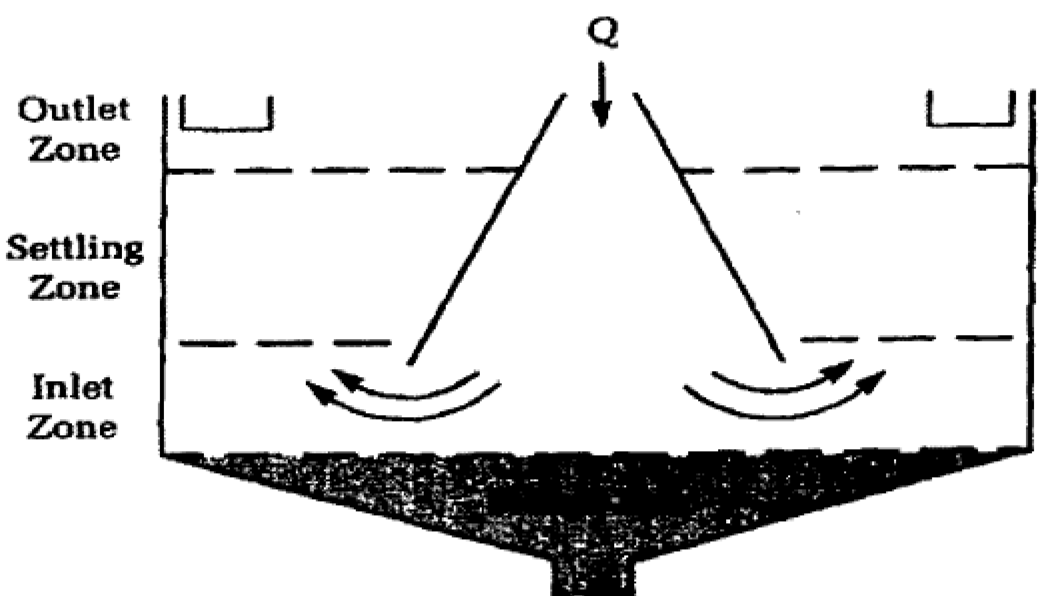
Rectangular and Circular sedimentation tanks



Rectangular tank

L:W = 4:1

W = 10 m is common



Circular tank

Max. 60 m diameter

Factors affecting sedimentation and design criteria

Factors

- ❑ Size, shape and weight of the particles
- ❑ Viscosity and temperature of water
- ❑ Surface overflow rate (SOR = Q/BL)
- ❑ Inlet and outlet arrangements
- ❑ Deterntion period (t =V/Q) and actual time of flow
- ❑ Effective depth of settling basin (3m – 5m)

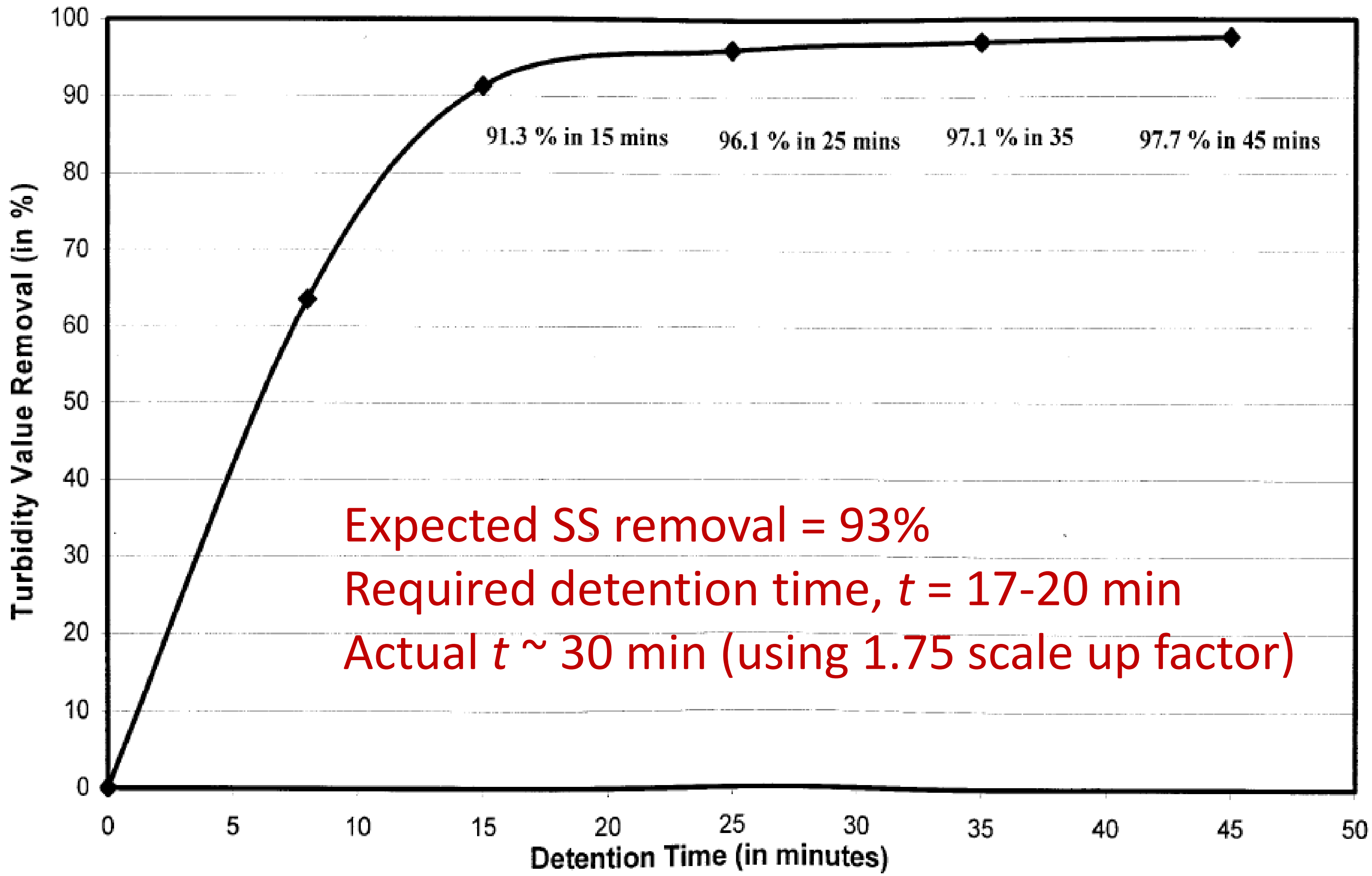
Design Criteria

- ❑ SOR = 450-800 litres/hr/m^2 (900-1200 litres/hr/m^2 for sedimentation with coagulation-flocculation)
- ❑ Detention time = 1 – 10 hrs, hor. velocity = 15 cm/min (max)

Eckenfelder recommends a scale up factor of 0.65 for SOR and 1.75 for detention time

Case study: Keranigonj SWTP

Flocculant Settling column test results for the Padma River water (Aluminum sulfate used as a coagulant)



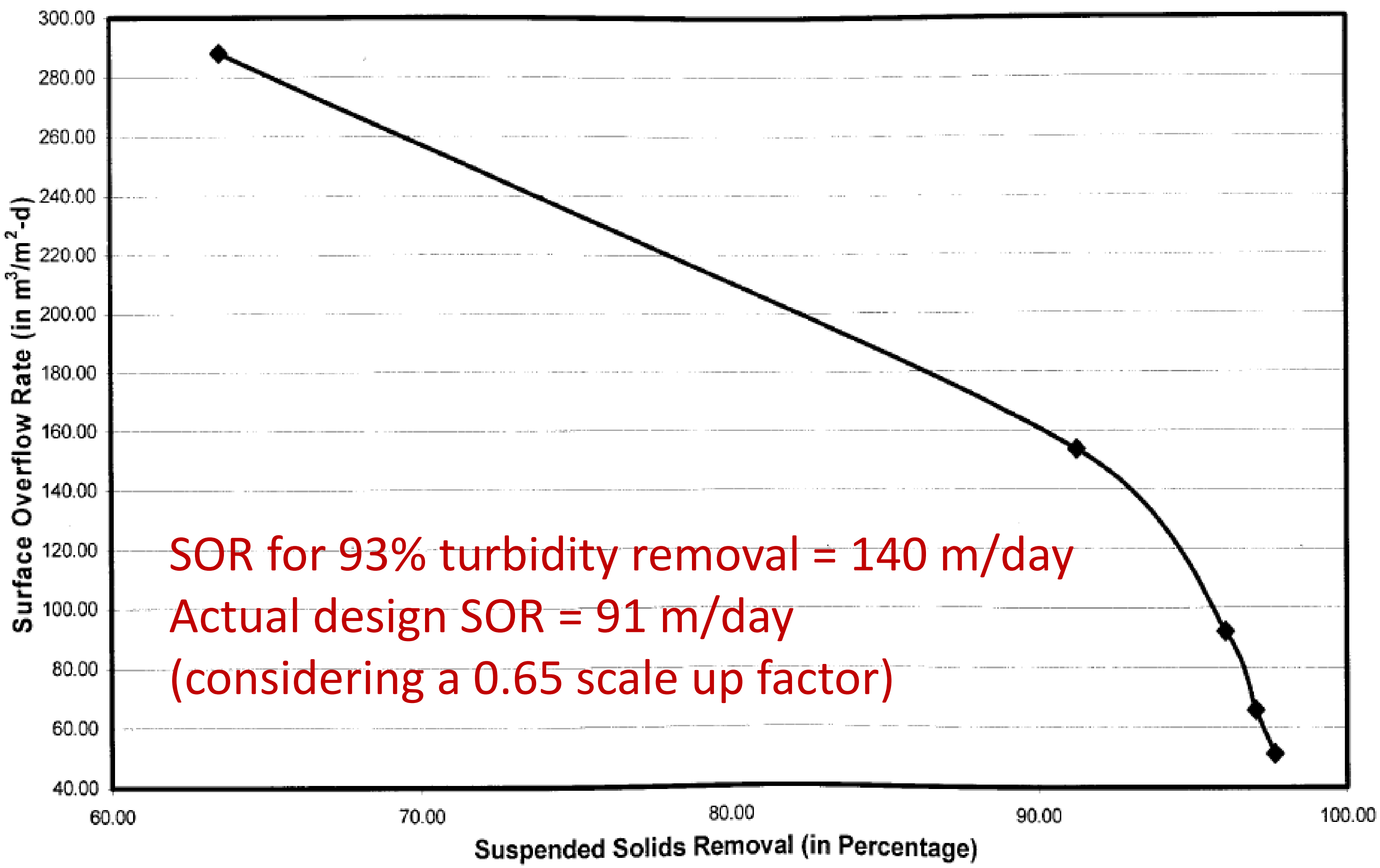
Expected SS removal = 93%

Required detention time, *t* = 17-20 min

Actual *t* ~ 30 min (using 1.75 scale up factor)

Case study: Keranigonj SWTP

Flocculant Settling column test results for the Padma River water (Aluminum sulfate used as a coagulant)



Flotation

A solid-liquid separation process that transfers solids to the liquid surface through <u>attachment of bubbles to solid particles</u>

<u>Process Variables</u>

Design	Operational	
	Physcial	Chemical
• Hydraulic loading • Solids loading	• Recycled flow • Operating pressure air quantity • Solids removal frequency	• Coagulant dose • pH • Influent solids concentration

<u>Flotation systems:</u>

1) Dissolved air flotation
2) Dispersed air flotation
3) Electrolytic flotation