WATER TREATMENT EAP215/3 WATER SUPPLY AND TREATMENT ENGINEERING

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References:

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- 3. Water Quality and Treatment-A Handbook of Community Water Supplies, 5th Edition, AWWA, McGrawHill
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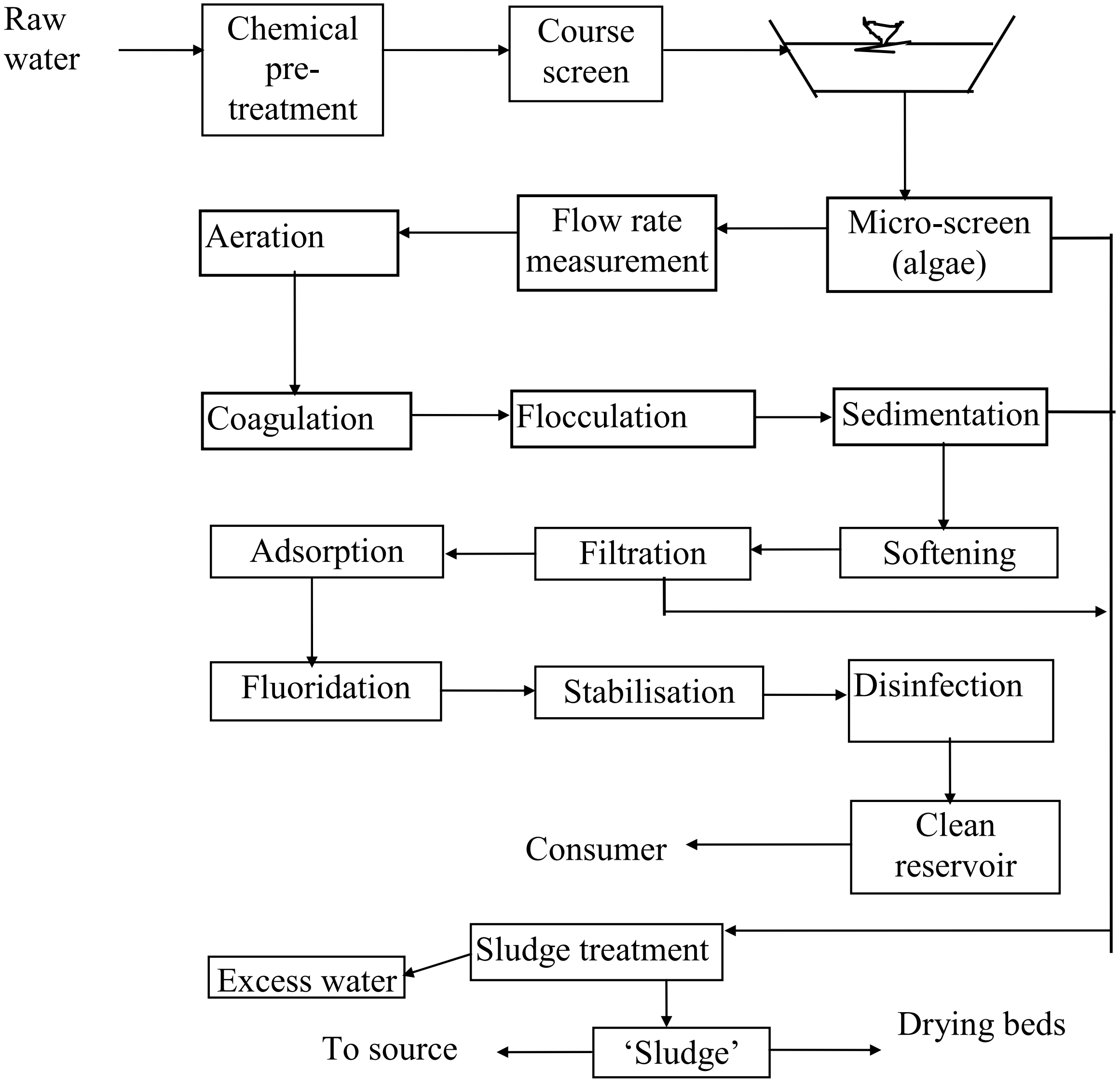
Typical Water Treatment Process



Raw water

Chemical pre-treatment

Course screen

Micro-screen (algae)

Flow rate measurement

Aeration

Coagulation

Flocculation

Sedimentation

Softening

Filtration

Adsorption

Fluoridation

Stabilisation

Disinfection

Clean reservoir

Consumer

Sludge treatment

Excess water

'Sludge'

To source

Drying beds

Why water needs to be treated

- Palatable and pleasant to drink
- No colour and smell
- Free of pathogenic organisms
- Not corrosive – affecting humans as well as equipment

Classes of Treatment

Class	Treatment	Water source
A	No treatment	Spring water found in hilly areas and used individually
B	Disinfection	Spring water found in hilly areas and used by the public
C	Normal treatment process	River and impounded reservoir (upstream and downstream of the river)
D	Special treatment	Need to remove pollutants such as colour, algae, organic and inorganic matters from the river or lake water . Water for special industrial use.

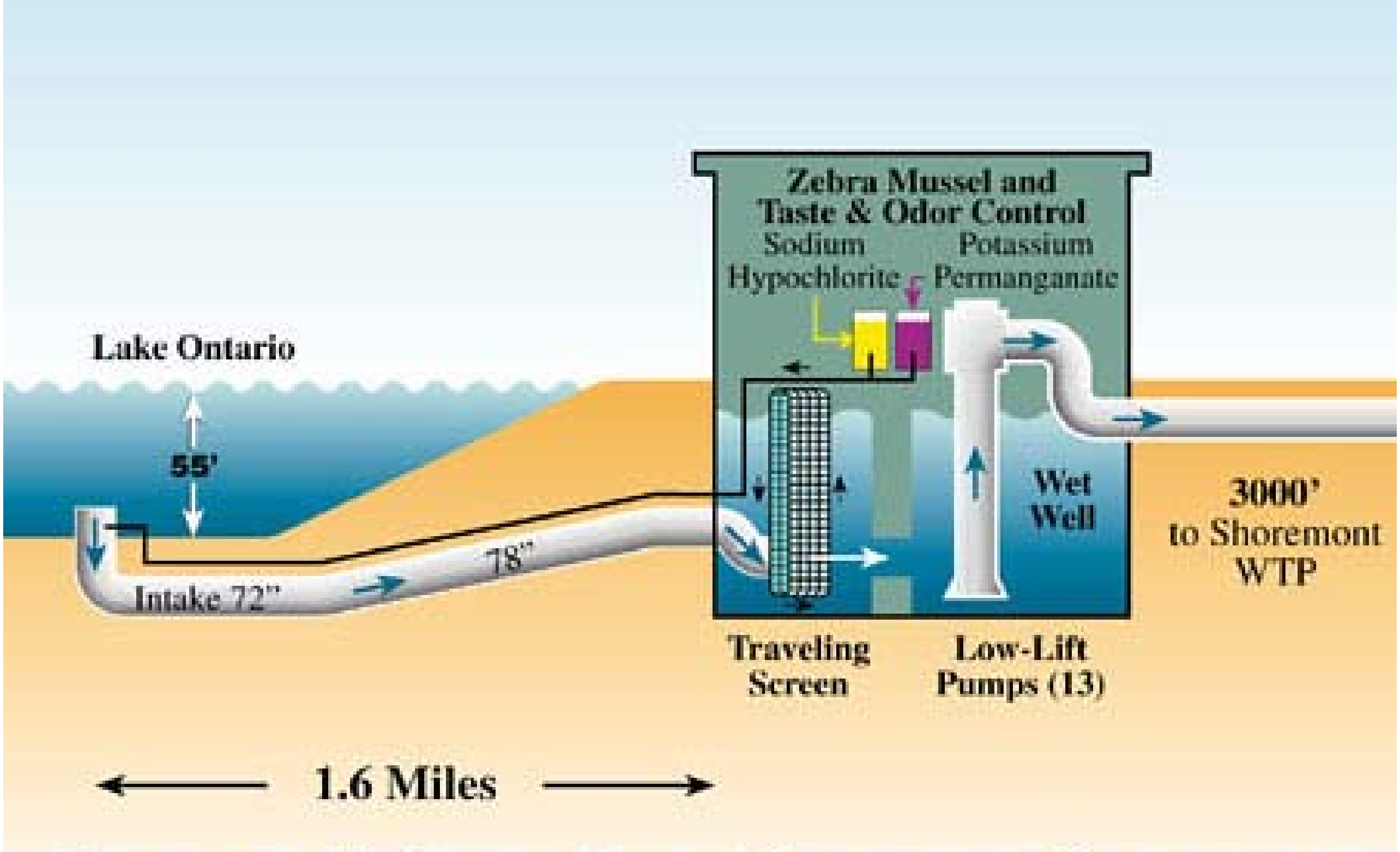
Propose treatment process

Parameters	Treatment process
Suspended solids	Course screen and fine screen
Dissolved solids	Micro-screen
Algae	Micro-screening, pre-chlorination, copper sulphate, carbon adsorption, rapid filter
Turbidity	Coagulation, flocculation, sedimentation, or dissolved air flotation
Colour	Coagulation, flocculation, filtration, carbon adsorption
Taste and smell	carbon adsorption, chlorination
Hardness	Coagulation, filtration, lime softening

Parameters	**Treatment process**
Iron and manganese :	
>1 mg/L	Pre-chlorination
<1 mg/L	Aeration, coagulation, filtration
Pathogen (MPN/100mL)	
<20	Post chlorination
20-100	Coagulation, filtration, post chlorination
>100	Pre-chlorination, coagulation, filtration, post chlorination
Free ammonia	Adsorption, post chlorination

Pre-treatment

- Raw water storage
- Screen
- Pre-chemical treatment
- Aeration
- Pre-sedimentation



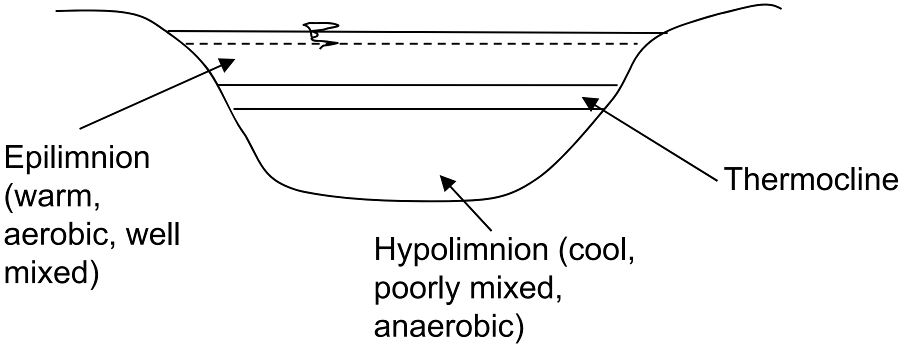
INTAKE & LOW-LIFT PUMPING STATIONS

Raw Water Storage

- To even out variations in flow
- To improve the water quality
- To even out the variations in water quality
- When water is stored in a reservoir for a period of 1 month to several months – there is a great decrease in pathogenic organisms. Even a few day will improve its physical and microbiological characteristics.

- Storage in the form of impounded reservoir or a small open storage reservoir.
- Improvement is a result from natural settling of suspended solids.
- Storage to improve water quality should be equivalent to 7-15 days of average water demand
- Problems: siltation, eutrophication

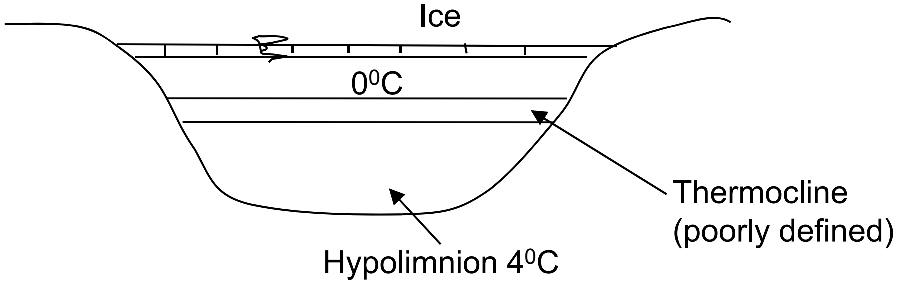
Stratifications of lake during summer and winter



Epilimnion (warm, aerobic, well mixed)

Thermocline

Hypolimnion (cool, poorly mixed, anaerobic)



Ice

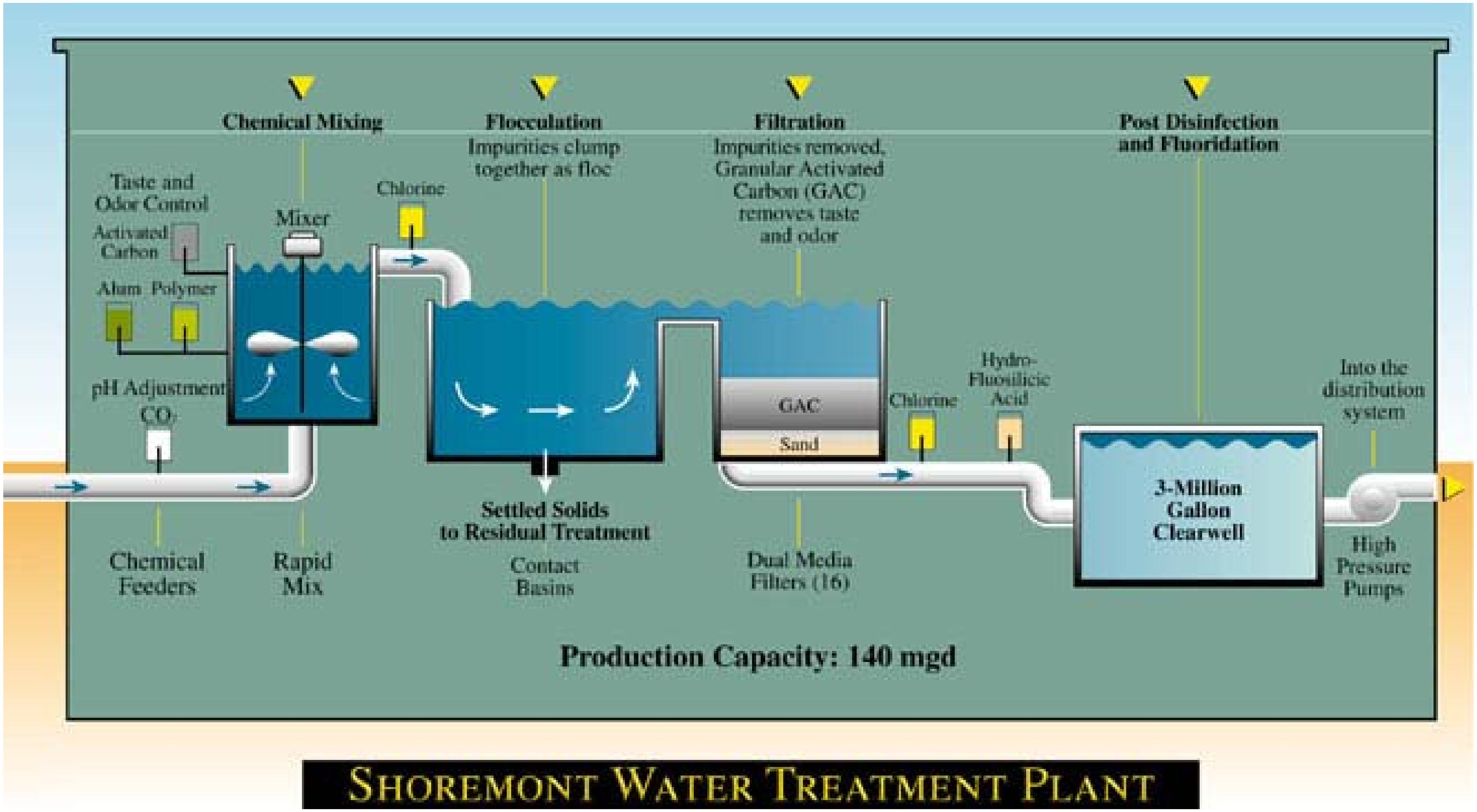
0^0C

Thermocline (poorly defined)

Hypolimnion 4^0C

Thermocline layer may be defined as a change in temperature with 1m depth with greater than 1^0C. The depth of epilimnion is related to the size of the lake and could be as little as 1 m in small lake besides the storm activity in spring when stratification is developing (Davies and Cornwell, 1998). Arhonditsis and Brett (2005) reported that the level of dissolved oxygen at the epelimnion layer for Lake Washington was as high as 11 mg/L in March to as low as 9 mg/L in August for the reporting years 1995 to 2001. For the same period the observed values of total phosphorus and total nitrogen were at the higher range of 22 ug/L and 450 ug/L respectively in May

Treatment process



Chemical pre-treatment

- -to destroy algae using copper sulphate
- -to kill bacteria using chlorine especially during the outbreak of cholera etc.
- Chemicals will be dosed as the raw water enters the treatment plant

Course screen

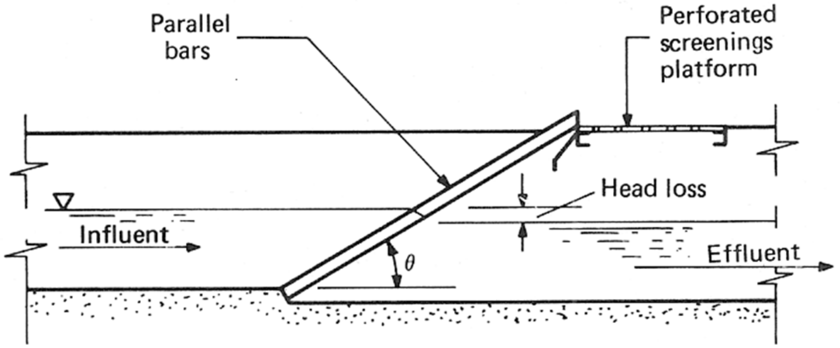
- To screen large material such as leaves, debris and other sizeable clogging materials.
- Trash racks:
- Clear opening 75 to 100mm
- Inclined or vertical
- Manually or mechanically cleaned

- Bar racks:
- Clear opening 20mm to 75mm
- Inclined or vertical. Normally inclined at 30^0 from vertical
- Manually or mechanically cleaned

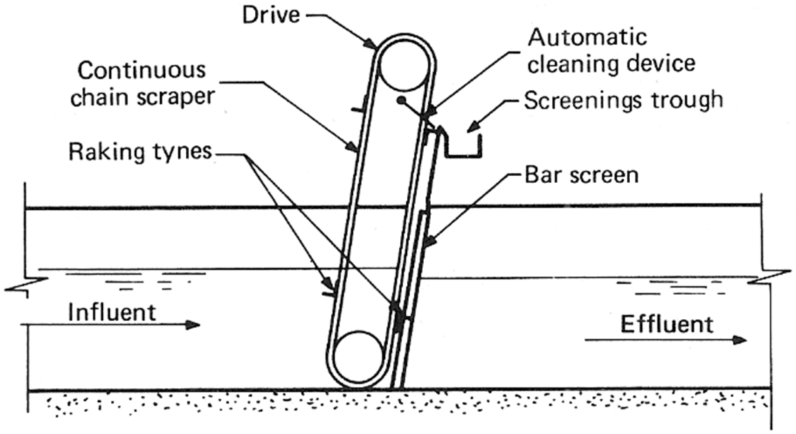
➢ Flow rate through the screen between 0.6 to 1 m/s, could be increased to 1.2 or 1.4 m/s at maximum flow.

Fine screen

- To remove materials too small to be deflected by course screen. Water velocity < 60cm/s at maximum design flow.
- Types:
- Traveling water screen – 6 to 9mm mesh cloth, normally installed after course screen.
- Basket screen – 1/8 in to ¾ in most common
- Dish or drum screen – vertical position, water spray cleaning


Parallel bars
Perforated screenings platform
Head loss
Influent
θ
Effluent

(a-i)


Drive
Automatic cleaning device
Continuous chain scraper
Screenings trough
Raking tynes
Bar screen
Influent
Effluent

(a-ii)

Drum screen (2m - 5m diameter) and micro-strainer (opening 15 to 64 microns)

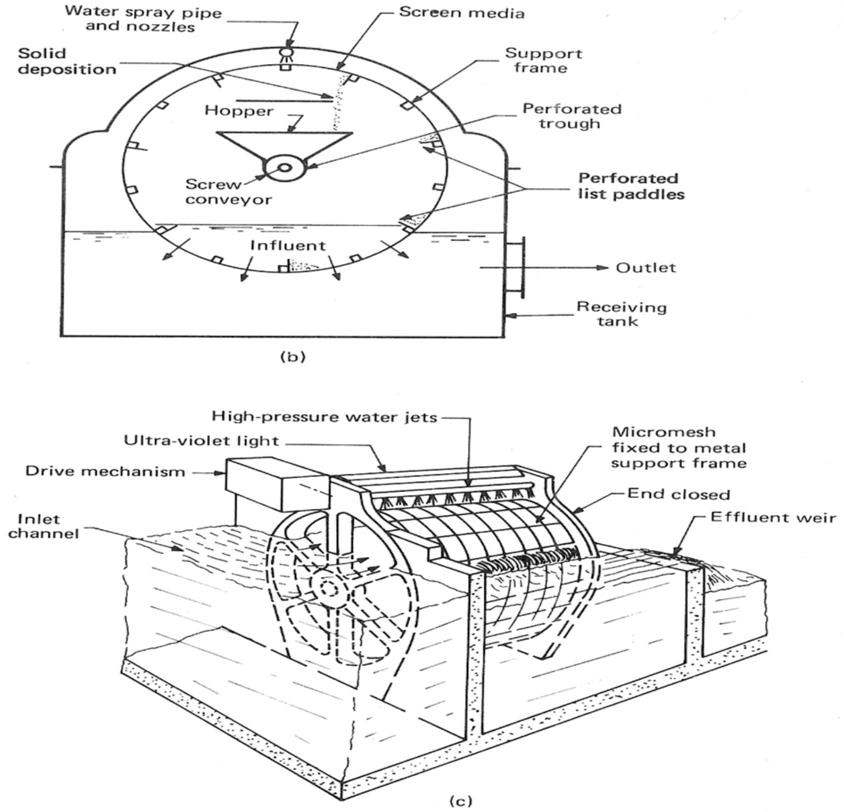
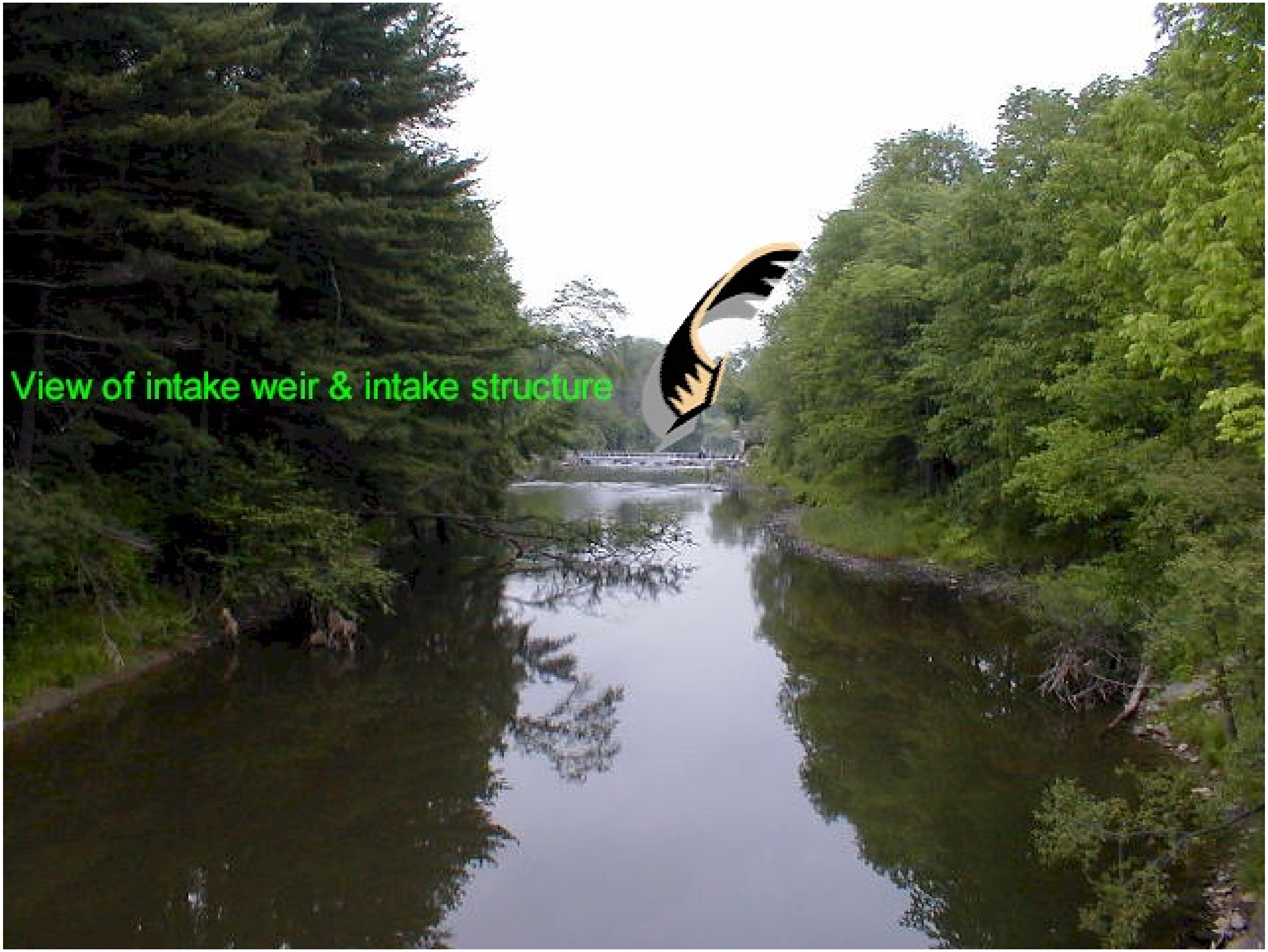
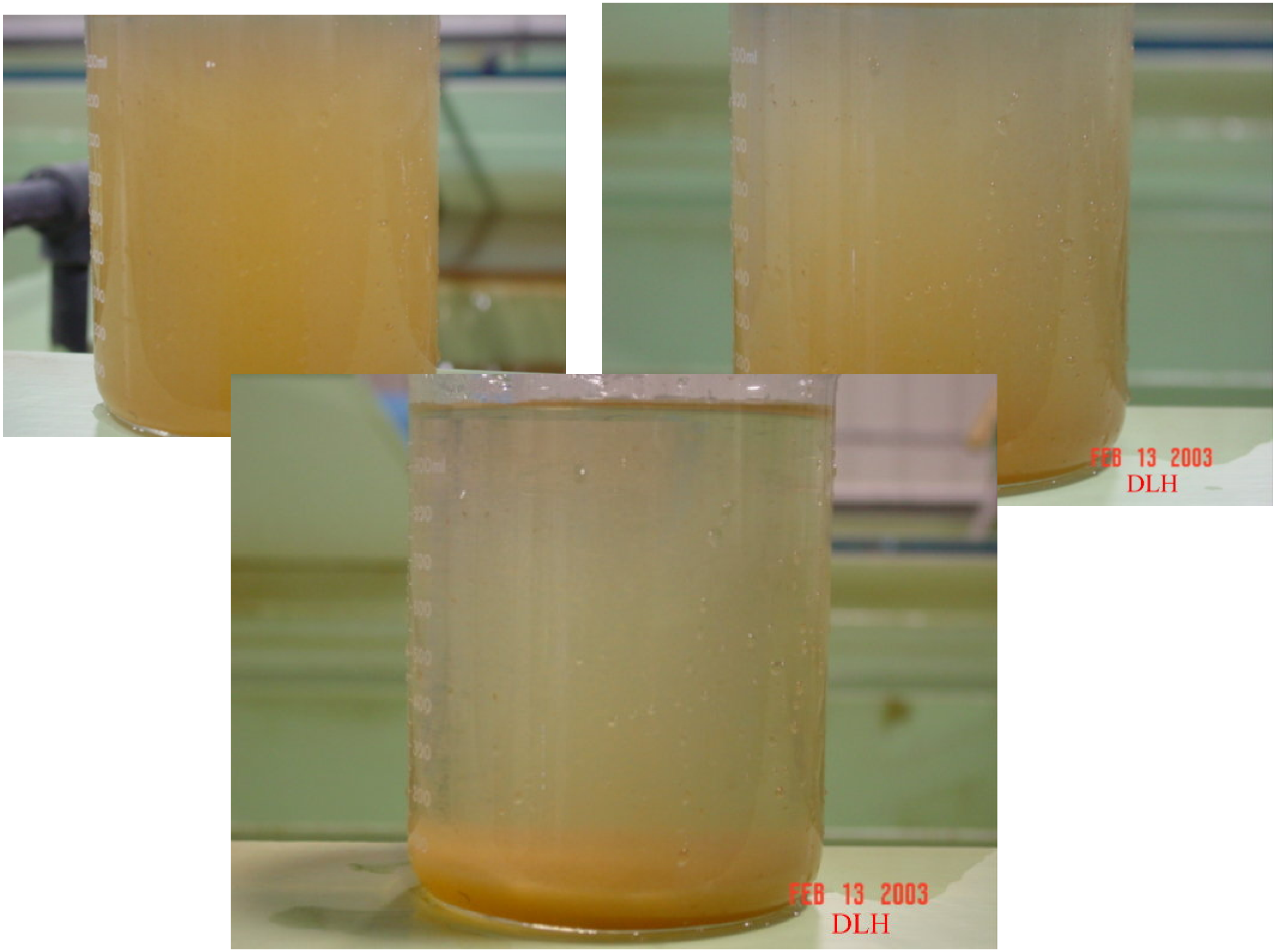


Fig 8.1 Examples of screens: (a-i) manually-raked bar screen, (a-ii) mechanically-raked bar screen, (b) drum screen, (c) microstrainer

Intake


View of intake weir & intake structure


FEB 12 2003
DLH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Aeration

- Increase DO in the water and removing dissolved gases such as carbon dioxide, methane and hydrogen sulphate
- Reduce taste and odour and corrosive property of water
- To oxidise iron and manganese

Types of aerators

- Water into air aerators – cascade aerator cone aerator, slat and coke tray aerator, draft aerator, spray aerator
- Air into water aerators – diffuse aerator, draft tube aerator
- Combination aerators – mechanical aerators, pressure aerator

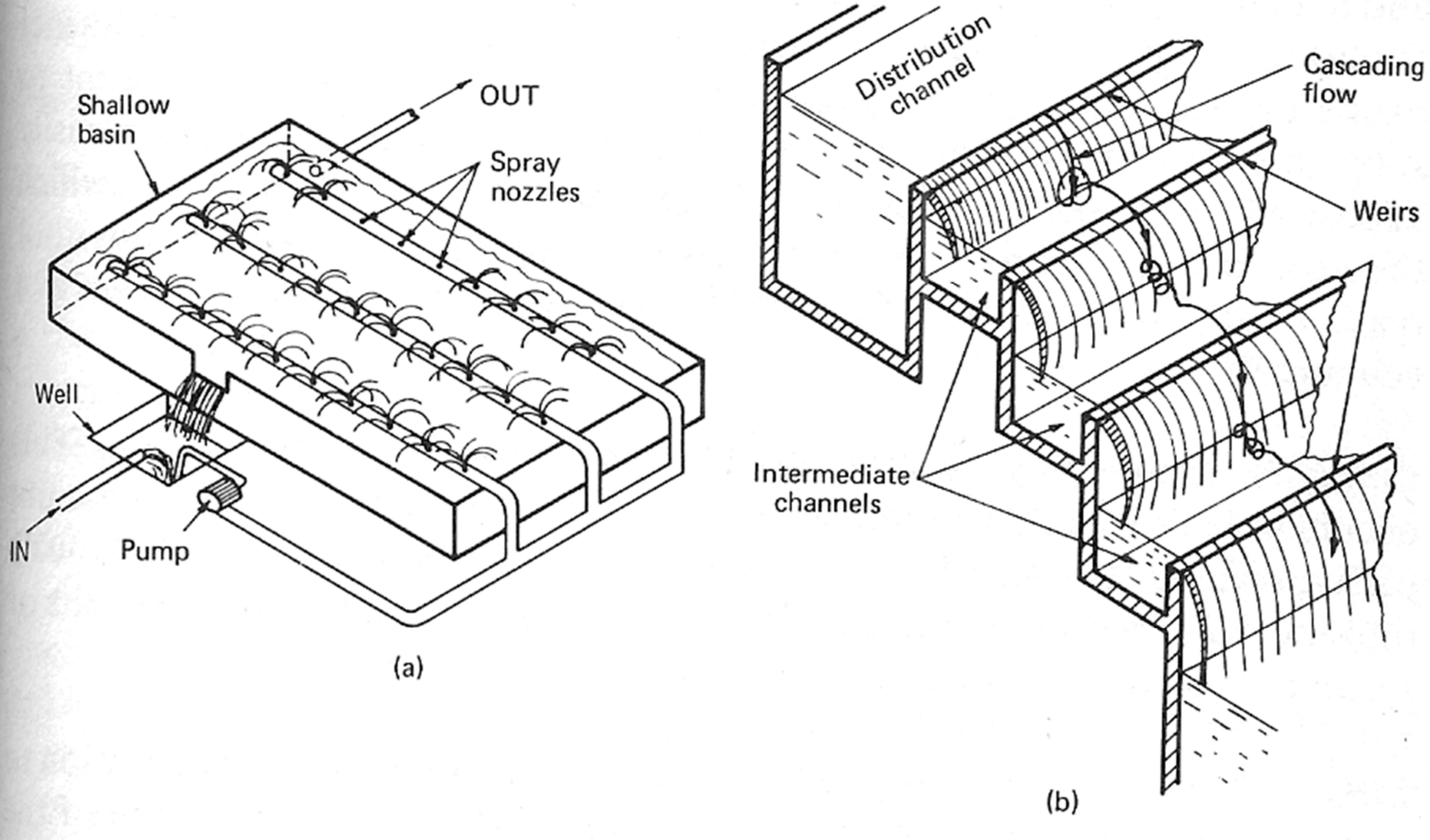


Fig 13.24 (a) Spray aerator, (b) cascade aerator

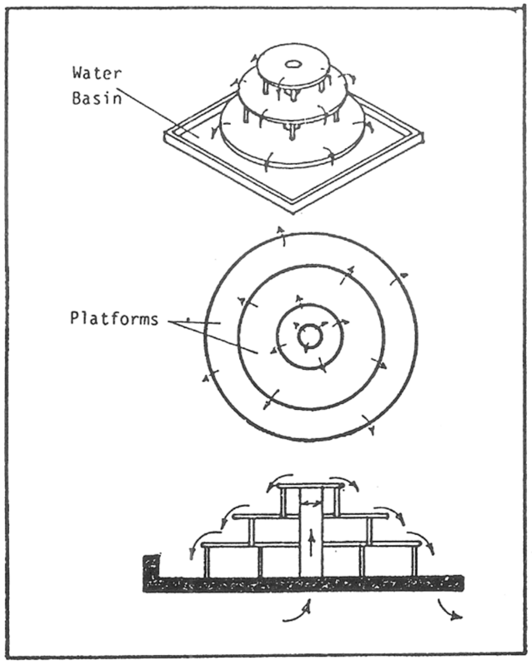


FIGURE 8.2 - MULTIPLE-PLATFORM AERATOR

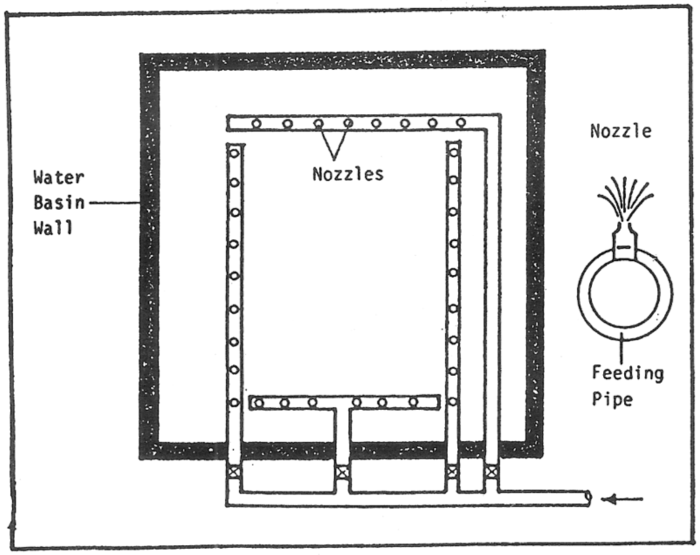


FIGURE 8.3 - SPRAY AERATOR

Examples of air-into-water aerators are:-

(a) venturi aerators, and
(b) draft tube aerators.

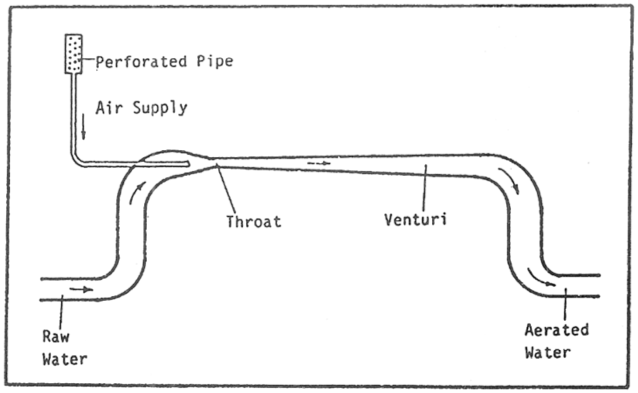


FIGURE 8.4 - VENTURI AERATOR

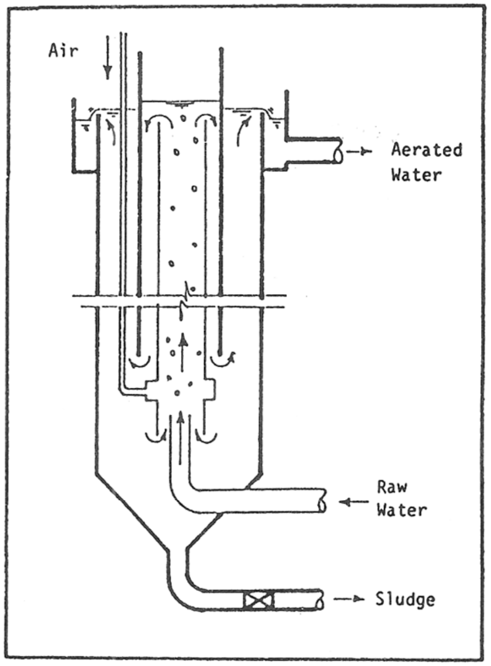
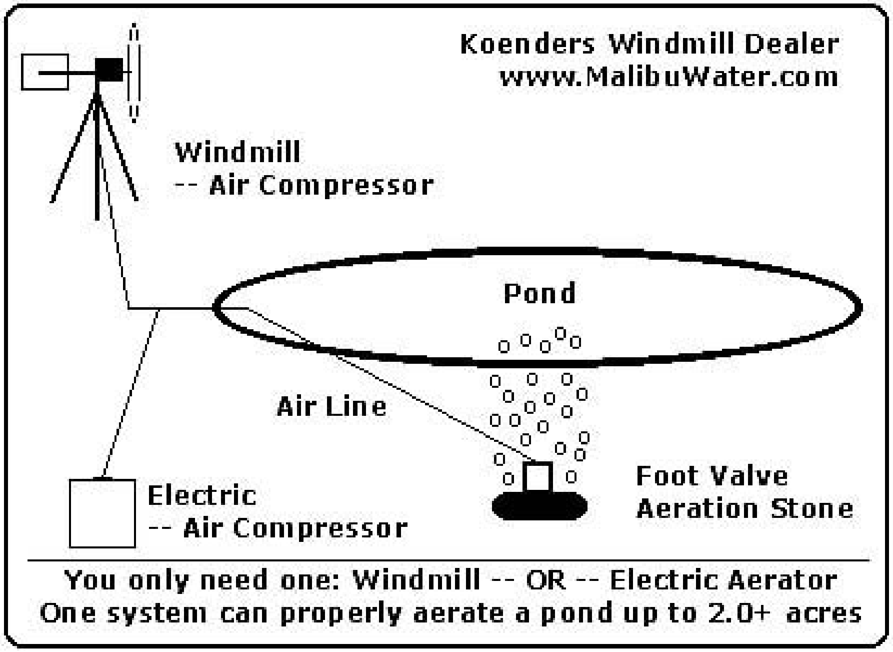
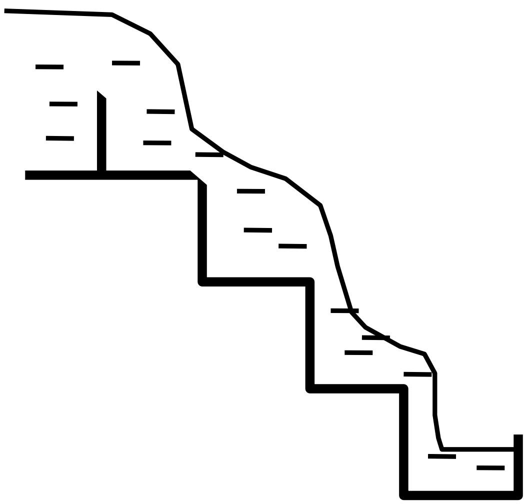
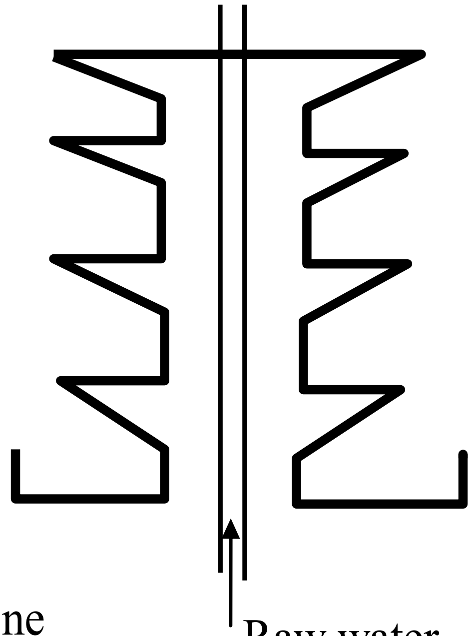


FIGURE 8.5 - DRAFT TUBE AERATOR

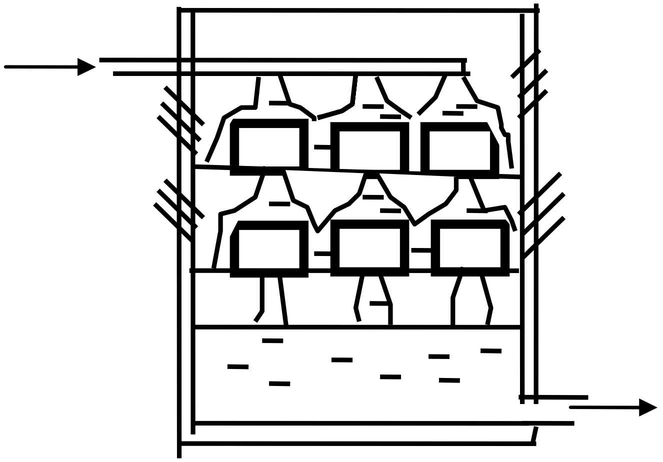




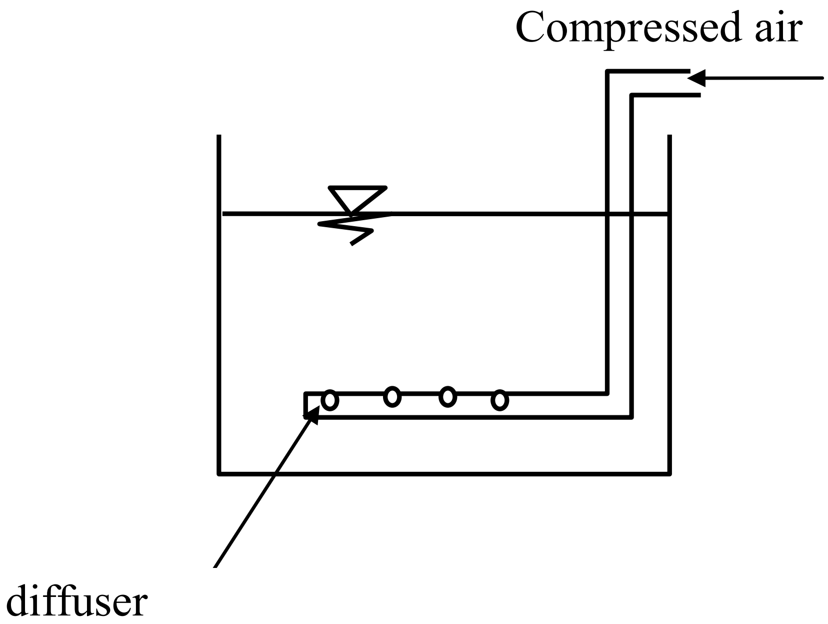
Cascade

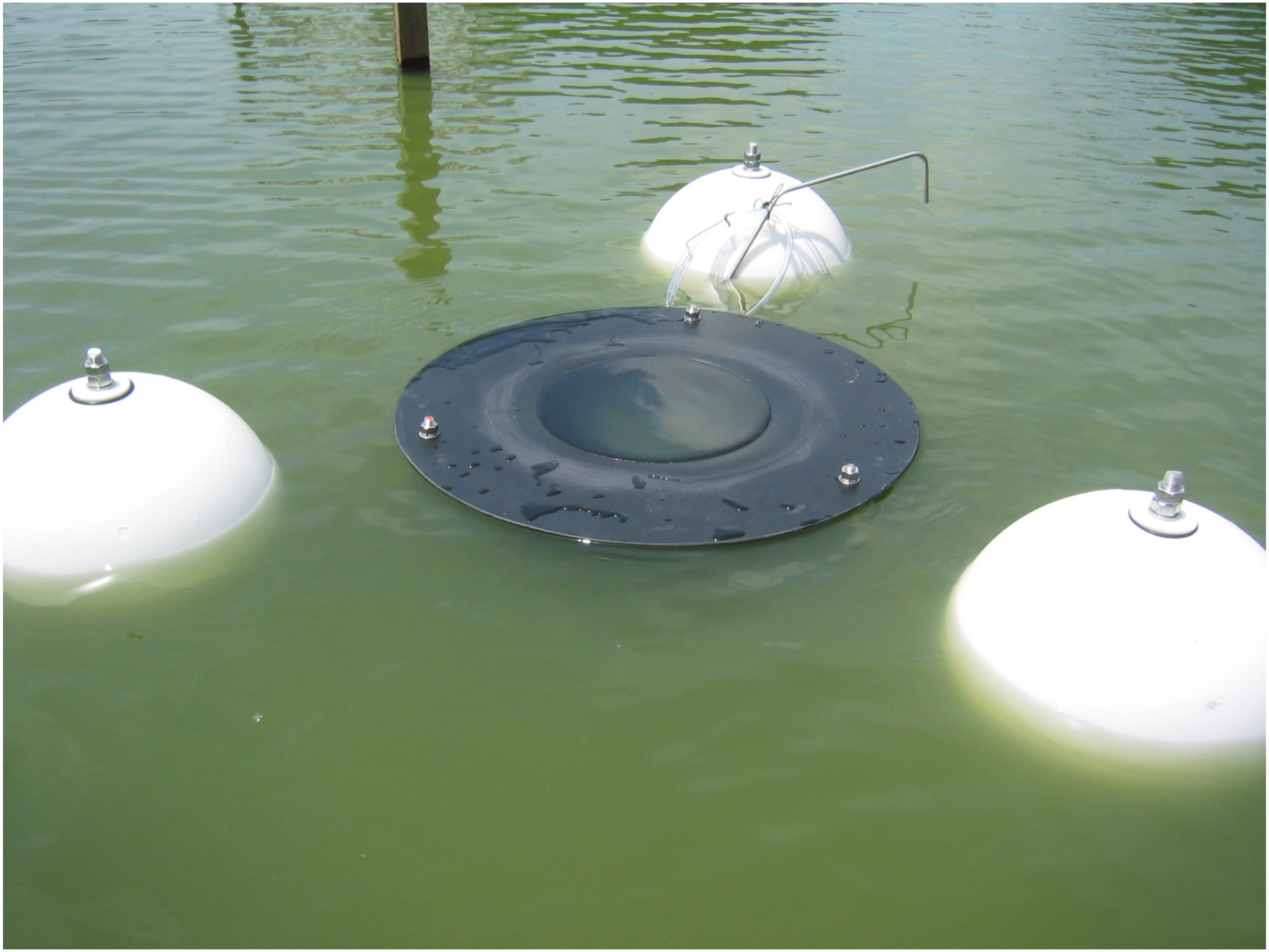


cone



Sprayer with combination of cascade & draft





Pre-chemical treatment

- (i) pre-chlorination
- Raw water is contaminated but not so turbid
- To control algae and other micro-organisms
- Dose around 1 mg/L
- (ii) copper sulphate treatment
- To control algae and aquatic plants

- Certain freshwater algae are toxic, e.g. blue-green algae will cause colouration, corrosion of concrete and steel and toxic to freshwater. Others are green, diatoms, flagellate.
- Dosage depends on temperature and alkalinity, normally at 0.12 mg/L to 0.3 mg/L .
- Safe dosage for most aquatic fish at 0.5 mg/L

2. RAPID MIX

- The desired reactions between the coagulant and water are irreversible and take place in a fraction of a second.
- mixing must be very fast.
- Coagulant should be injected at the eye of the impeller for maximum turbulence.

----------------------RAPID MIX

- The loss of head through the mixing stage is low, but the electrical equipment adds to the maintenance work.
- The power required is 3 to 15 watts per l/s.

Rapid mixing - coagulation

- Two types:
- 1. Mechanical – propeller or paddle type mechanical mixers.
- 2. Hydraulic – V notch weirs, Parshall flumes, orifices, throttles valves etc.

Mechanical mixer

- Typical design values for most mechanical rapid mix system provides detention time t of 10 to 60 sec and G values of 600 to 1000s^{-1}.

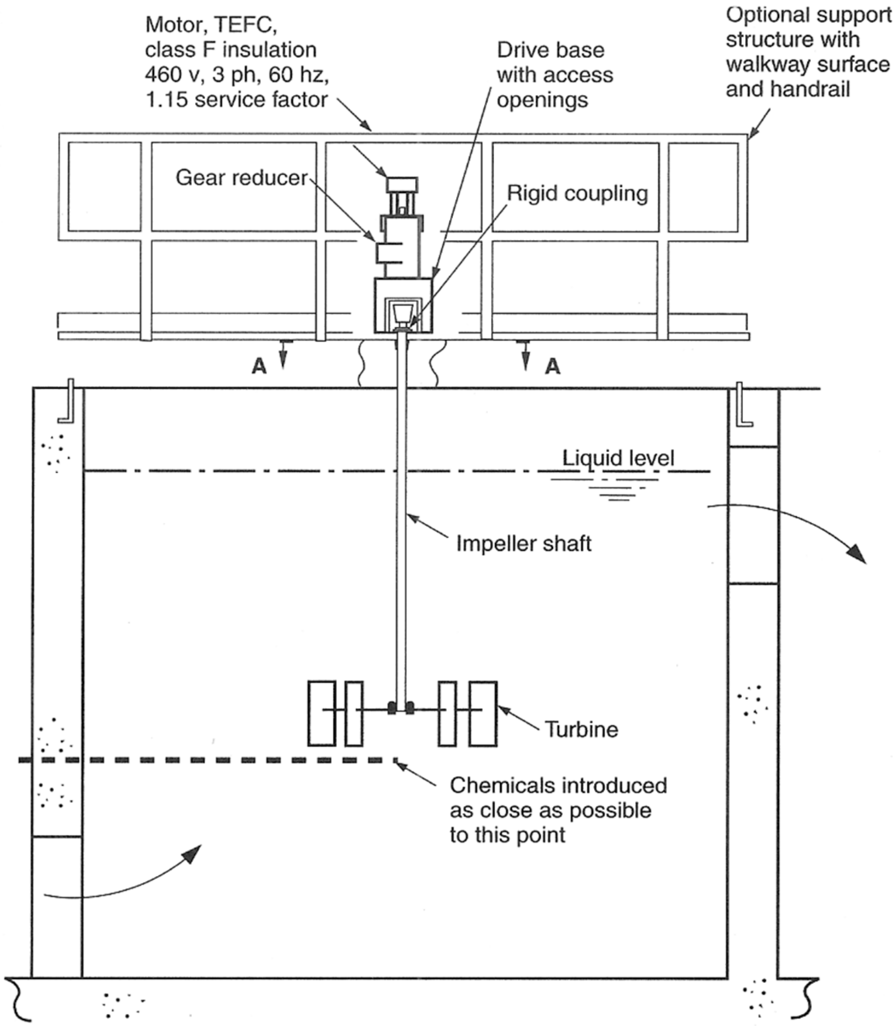


FIGURE 6.2 Turbine-type mechnical flash mixer. *(Courtesy of Eimco Process Equipment.)*

Hydraulic mixing:

- Baffles; high level of turbulence necessary.
- Weirs; injection from several points across width of channel.

- Hydraulic mixing:
- Total head loss across a throttled valve should not exceed 3.2m for mixing coagulant chemicals
- Energy provides by a weir with an effective fall of 30cm provides a G value of 1,000s^{-1} at 20^{0}C.
- Weir mixers normally use for flow rate <150 MLD due to maintenance problems with multiple orifice chemical feed manifolds.

---------------Hydraulic mixing

Baffles

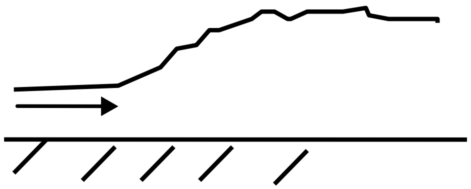
Weirs

--------------Hydraulic mixing

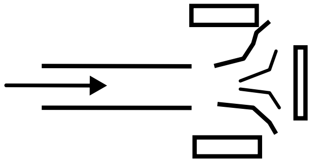
- Hydraulic jump – but at low flows much of the water may by-pass the turbulent ‘roller’.
- Jets.
- Orifice in pipeline

--------------Hydraulic mixing

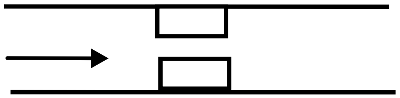
Hydraulic jump



Jets



Orifice



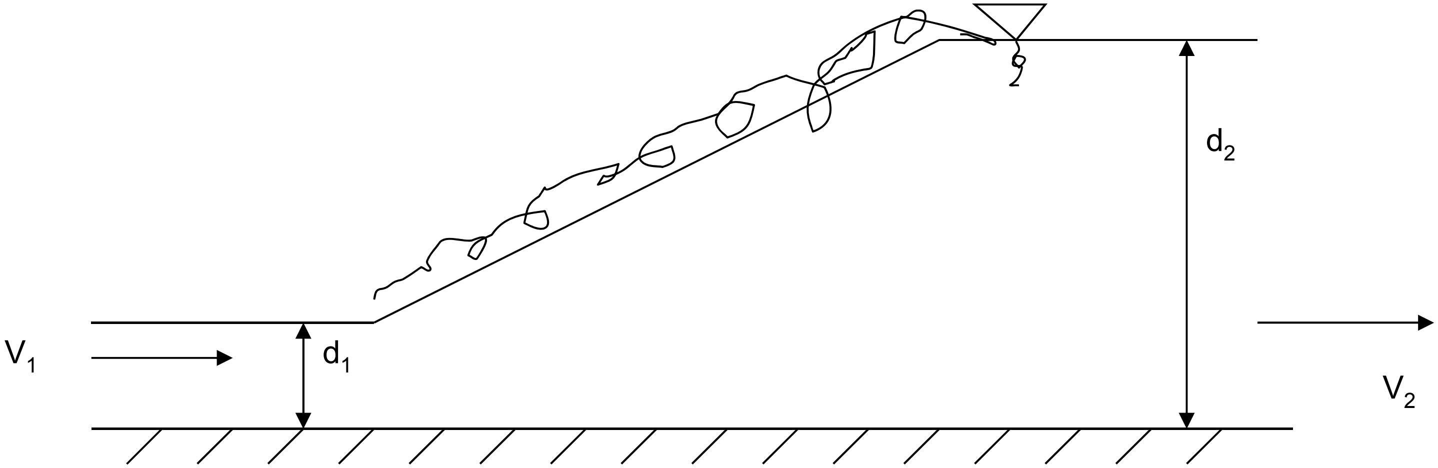
--------------Hydraulic mixing

- The sequence of dosing (if several chemicals are used) is best determined by experimentation at the plant concerned.
- If the chemical is dosed under water, the system should be designed to allow visual inspection of the flow of coagulant.
- Air has been used to induce agitation, but the bubbles attached to flocs may prevent settlement.

Hydraulic jump

- Occurs when a supercritical flow meets a sub-critical flow
- The resulting flow transition is rapid and involves a large energy loss due to turbulence
- $F_r > 1$: supercritical flow; water velocity>wave velocity; disturbances travel downstream; upstream water levels are unaffected by downstream control
- $F_r < 1$: Subcritical flow; water velocity<wave velocity;disturbances travel upstream and downstream; upstream water levels are affected by downstream control

Hydraulic jump



Hydraulic Jump

$$\frac{d_1}{d_2} = \frac{1}{2}\left[\sqrt{\left(1 + 8F^2\right)} - 1\right]$$

Where:
d_1 = depth of H_2O upstream of the jump (m).
d_2 = depth of H_2O downstream of the jump (m).

F = Froude No. = $\dfrac{V_1}{\left(g d_1\right)^{\frac{1}{2}}}$

where V_1 = velocity of flow upstream of the jump (m/s)
g = 9.81 m/s^2.

For a jump:

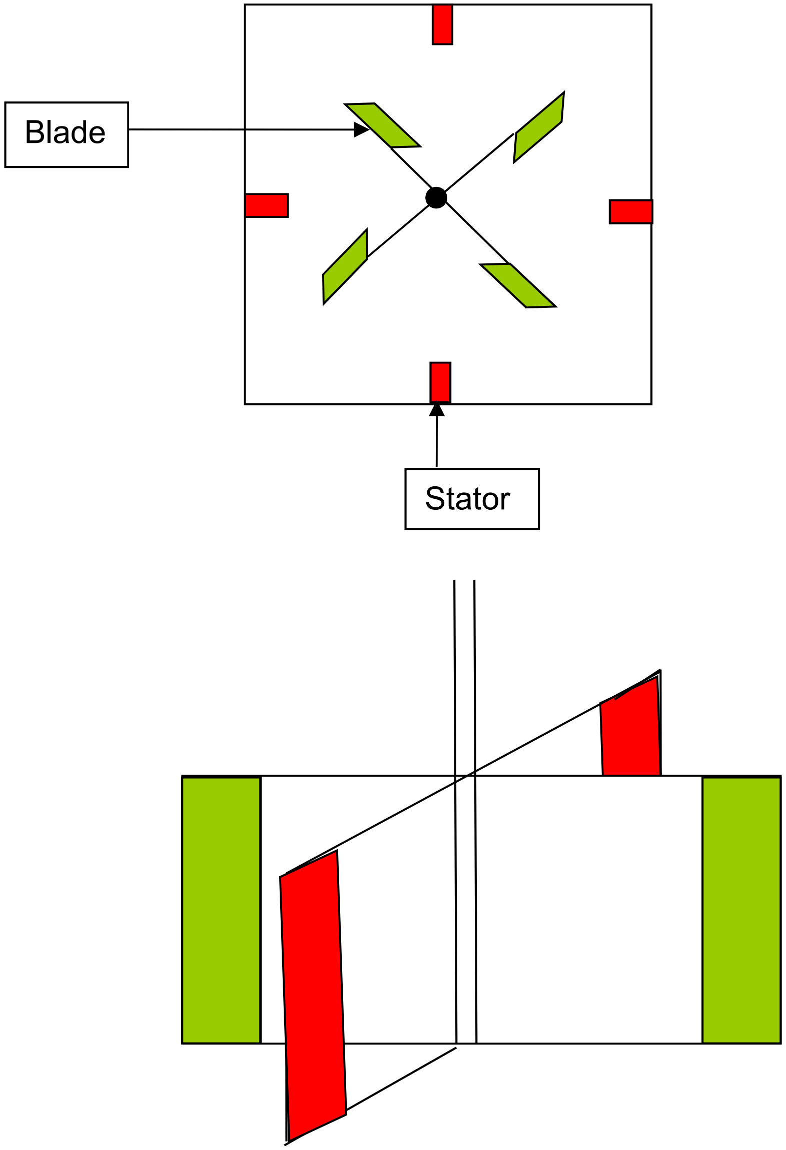
$$\frac{d_2}{d_1} > 2.4$$

$$F_r > 2$$

When Fr between 4 & 9, the energy consumed in turbulence can be between 45 & 70%, which is adequate for rapid mixing. The head losses is typically 0.3m or greater

Criteria for Rapid Mixing:

- Performance of a square tank is better than cylindrical tank.
- Stator baffles may provide an advantage for appropriate mixing.
- Flat blade is better than propeller impeller.
- Introducing the coagulant at the axle of the agitator may encourage coagulation.


Blade
Stator

Mechanical rapid mixer

1. DOSING

- Dosing pumps (positive displacement) are calibrated to supply chemicals at a known rate .
- The calibration can be checked using a graduated tube.
- Lime is dosed as a slurry, not as a solution. For this reason it must be kept constantly agitated, and pipes conveying the slurry should be flushed with water regularly

DOSING

- For small works constant head devices can be used to dose chemicals .
- the head governing the flow is constant whatever the level of the solution in the container .
- Another system doses a fixed volume of coagulant each time a tank is filled.
- Plants without a power supply may use sodium carbonate to raise the pH since it can be dosed as a solution.

Terminology

- Suspension - a dispersion of solid particles in a liquid. These particles scatter light, making aqueous suspensions cloudy or turbid.
- Colloid -Colloidal particles are very small (1 to 200 x 10^{-9} m) and form stable suspension because the random brownian motion- of the water molecules is enough to prevent the particles settling .

-----------------Terminology

- Floc - a collection of colloidal particles held together.Flocs generally have little strength and a density close to the density of water.
- Coagulation -the process of making conditions favorable for colloidal particles to join together to form flocs by biological or chemical processes.
- Flocculation -is the growth of flocs

- In normal English, the term ‘coagulate’ means to ‘change from fluid to more or less solid state, clot, curdle, set or solidify’.
- Flocculate is a small portion of matter like a flock of wool.
- Source: Water and Wastewater Engineering System, Barnes et al., 1981, page 199.

Settling velocity for different particle sizes

Particle size (mm)	Size for	Settling velocity (ms^{-1})
10	Gravel	0.73
1	Course sand	0.23
0.1	Fine sand	1.0×10^{-2}
0.01	Silt	1.0×10^{-4}
0.0001	Large colloids	1.0×10^{-8} (0.3 m/year)
0.000001	Fine colloids	1.0×10^{-13} (3 m/million yr)

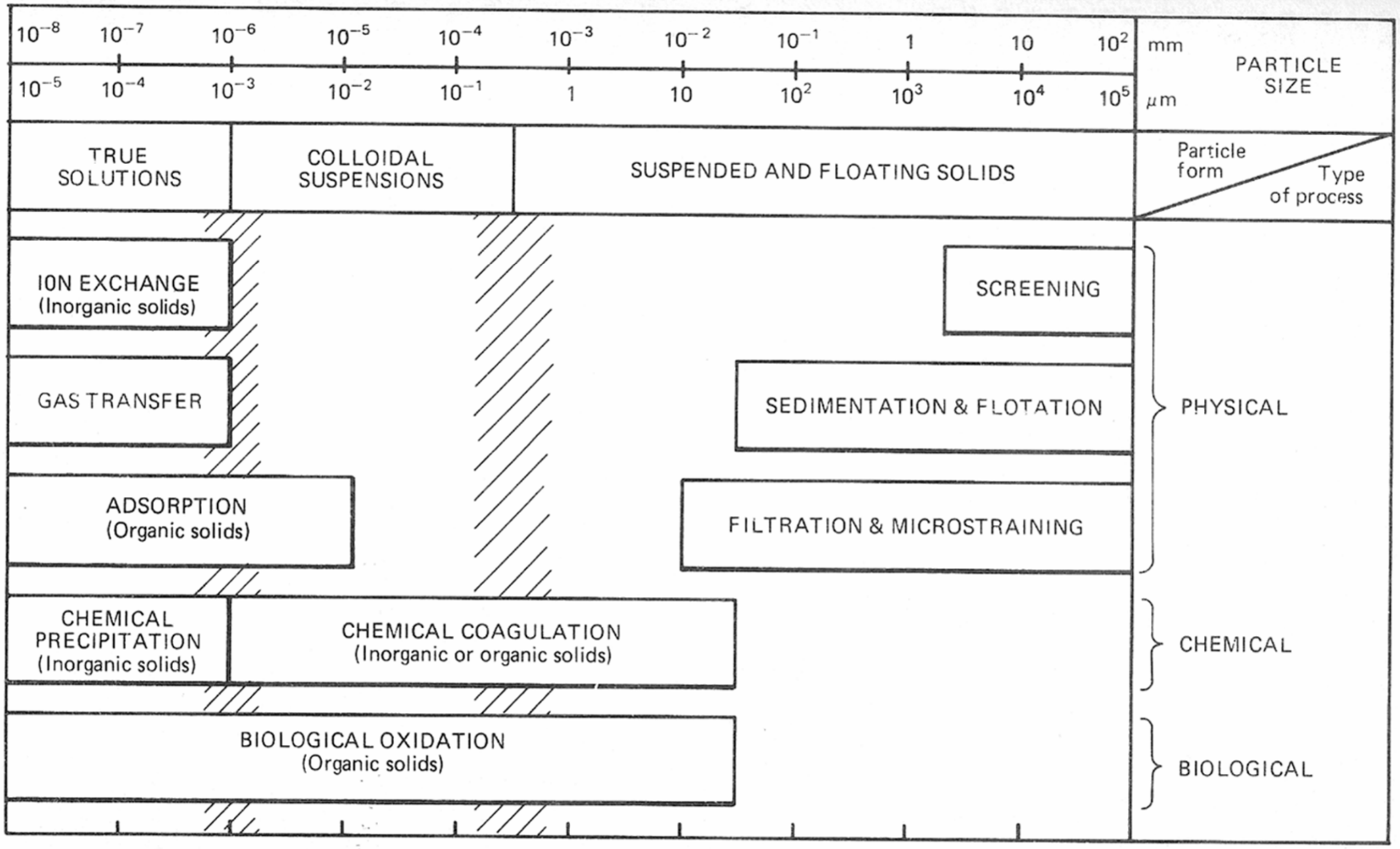
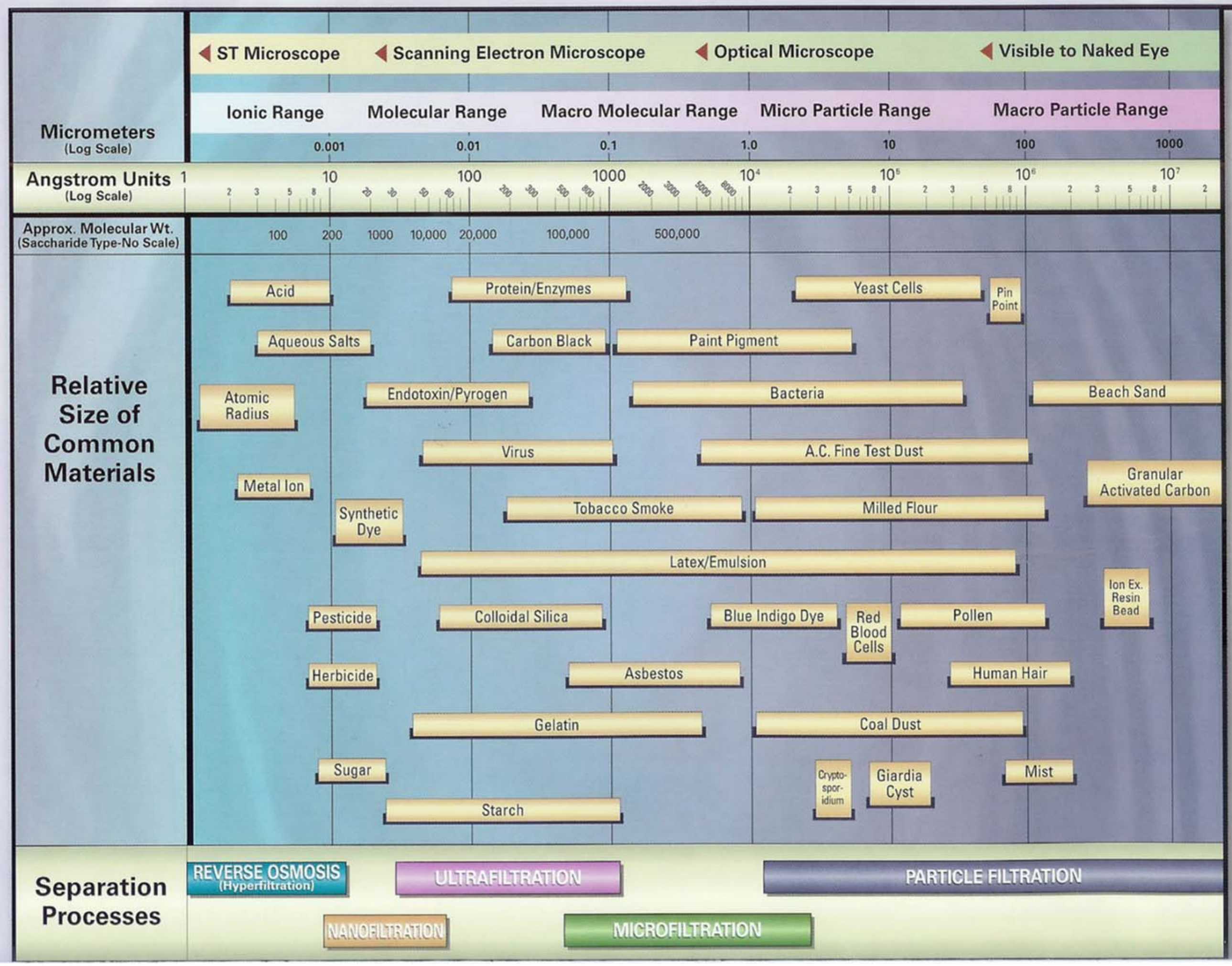


Fig 7.2 Applications of unit processes

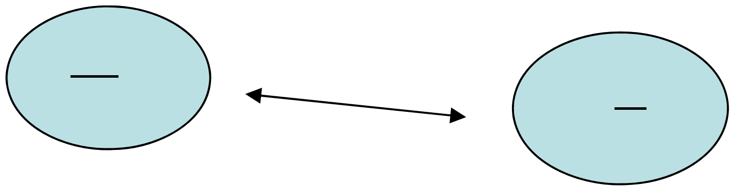
GE Osmonics

Filtration and Separation Spectrum



Coagulation -mechanisms

- In general colloidal suspensions in water consists of clay particles and other organic matters which have negative charges and always repel each others. Brownian motion prevents the settlement of particles under

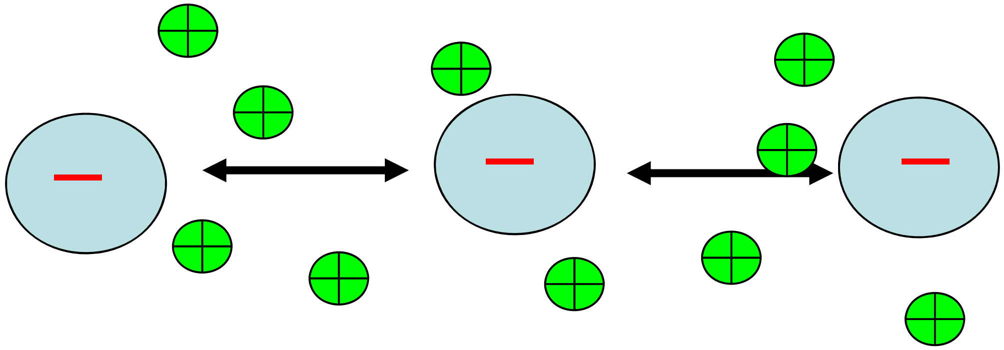


- Colloids may consist of:
- 1. colloidal clay – causes turbidity
- 2. large organic molecules – cause colour
- 3. proteins, carbohydrates and fats in sewage
- 4. oxides of iron, manganese and silica
- 5. precipitated aluminium hydroxide etc.

- Colloids are *hydrophilic* when the factor causing stability due to the attraction between particles and water. It means water loving. Such compounds have an affinity to water and are usually charged or have polar side groups to their structure that will attract water.
- Colloids are *hydrophobic* when no attraction between particles and water. It means water hating. These compounds are repelled by water and are usually neutral (no charge.)

- Hydrates of iron and aluminium form *hydrophobic* colloid in water.
- Proteins, starches or fats (*hydrophilic)* become stable as a result of mutual electrostatic repulsion.
- Colloidal particles have a very large ratio of surface area to volume. For e.g. 1cm^3 of material if divided into cubes of 10^{-5} mm on a side (mid-point of colloidal range) would have a surface area of 600m^2.

- Destabilisation has to be made by adding coagulants with positive charges.
- Thus reducing the repelling forces between the particles and promotes the agglomeration of colloids.



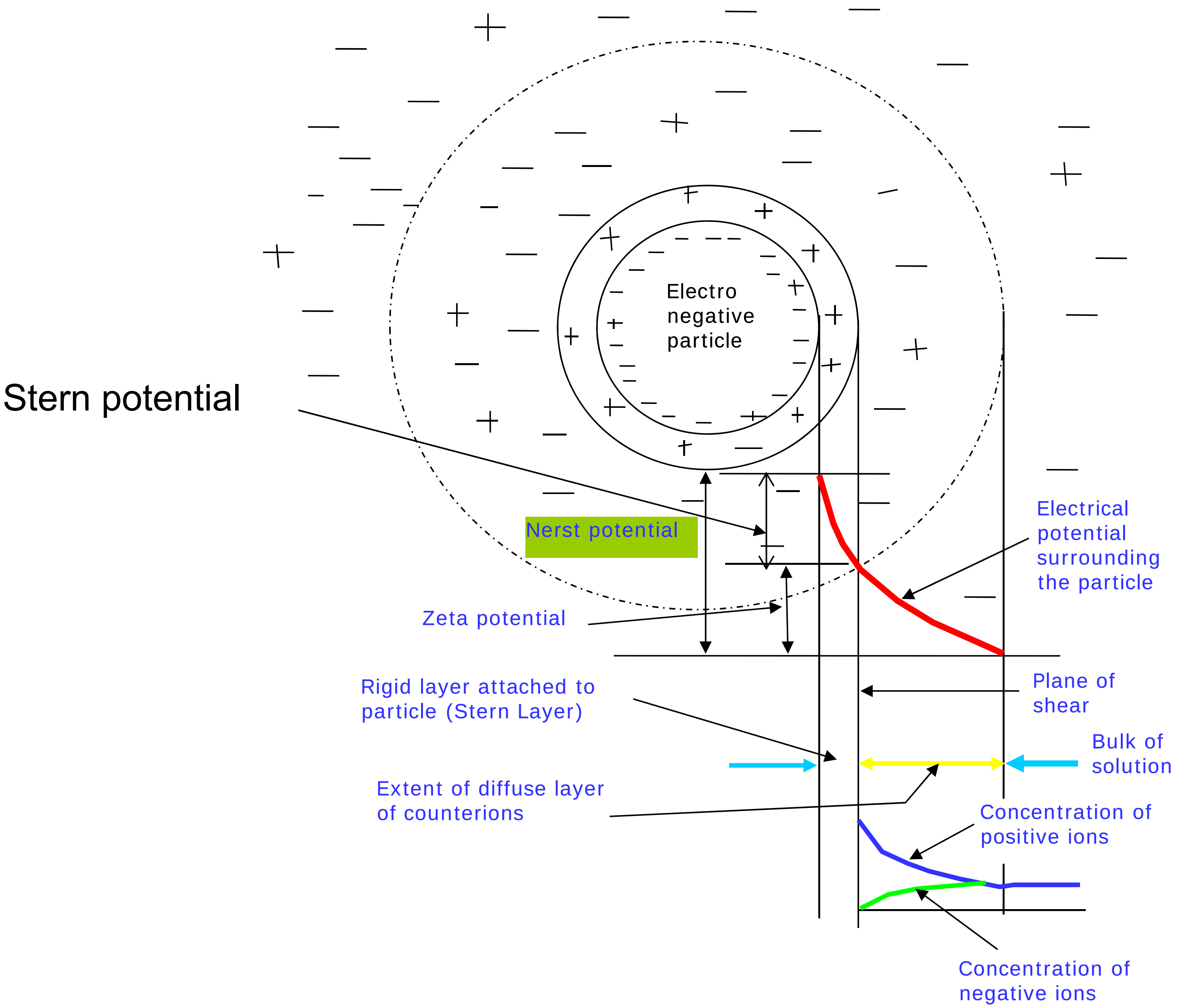
- The most well-known repulsive force is caused by the interaction of double layers of the surfaces (electrostatic stabilization)
- The most important attractive force is called the London-van der Waals force, which arises from magnetic field within the particles and in the space between them
- These two types of forces form the basis of the Derjaguin, Landau, Verwey, and Overbeek theory of colloid stability.

- Other forces include those associated with the hydration of ions at the surfaces (repulsive) and the presence of adsorbed polymers which can cause either repulsion (steric interaction) or attraction (polymer bridging).
- The repulsive force due to displacement of fluid (as particles approach one another on a collision course where the fluid between them must move out of the way) is called hydrodynamic retardation.

Guoy-Stern colloidal model (Figure in the next slide)

- Stationary charged layer on the surface is surrounded by a bound of water in which ions of opposite charge drawn from the bulk solution produce a rapid drop in potential. This drop within the bound-water layer is called stern potential.
- A more gradual drop, called zeta potential, occurs between the shear surface of the bound-water layer and the point of electro-neutrality in the solution

Negatively charged particle, the diffused double layer and location of zeta potential



Stern potential

Electro negative particle

Nerst potential

Electrical potential surrounding the particle

Zeta potential

Rigid layer attached to particle (Stern Layer)

Plane of shear

Bulk of solution

Extent of diffuse layer of counterions

Concentration of positive ions

Concentration of negative ions

CHEMICALS

- Alum - widely used as a primary coagulant. available as lumps, grains or powder, or as a solution which is strongly acidic .
- For optimum floc formation the pH should generally be between 6 and 8 .
- Acid is formed when alum reacts with water.
- 1 mg/l alum reacts with 0.39 mg/l 95% hydrated lime as $Ca(OH)_{2.}$.

Iron salts

- Operate over a wider pH range than alum.
- Iron flocs are heavier than aluminium flocs but may be harder to remove from filter sand.
- Ferrous sulphate is sometimes cheaper than alum because it is a byproduct of steel pickling. It must be oxidised to the ferric state usually by chlorine, when the two are known as chlorinated copperas.
- Ferric sulphate and ferric chloride may also be used.

Coagulant dosage

Coagulants	**Dose (mg/l)**
Aluminium Sulphate (Alum) $Al_2 (SO_4)_3.18H_2O$	10 – 50
Ferric Sulphate $Fe_2 (SO_2)_3$	10 – 50
Sodium Aluminate $Na_2 Al_2 NO_4$	5 – 30
Ferrous Sulphate $FeSO_2$	5 – 25

pH correction

- is necessary to raise the pH, and hydrated lime is usually preferred for this purpose on cost grounds.
- However lime has a low solubility and so is usually fed as a slurry-needs constant agitation.
- Where constant agitation is not provided sodium carbonate (washing soda) is used, because it dissolves readily in water.
- Sulphuric acid is used if the pH must be lowered.

Coagulant aids

- (i) Polyelectrolytes are used to make flocs larger, tougher and denser. They have long molecules with charged sites.
- Three types of polyelectrolytes: cationic, anionic and nonionic or ampholytic.
- The best type must be chosen by experiment.
- Polyelectrolytes may be used to reduce the requirement for coagulant and alkali.

-------------------Coagulant aids

- Synthetic polyelectrolytes (e.g. polyacrylamides) are banned in some countries, because the monomer an impurity is a health hazard.
- (ii) Activated silica produces a similar result to polyelectrolytes, but must be prepared with great precision.
- (iii) Purified clays may be added to waters with low turbidity or high colour to add weight to the flocs and reduce the coagulant requirement.

FLOCCULATION

Laminar settling: Stokes' law $$V = \frac{g}{18}\frac{(\rho_s - \rho_l)}{\mu} d^2$$

Where V is settling velocity

ρ_s is density of particle

ρ_l is density of liquid

d is diameter of particle

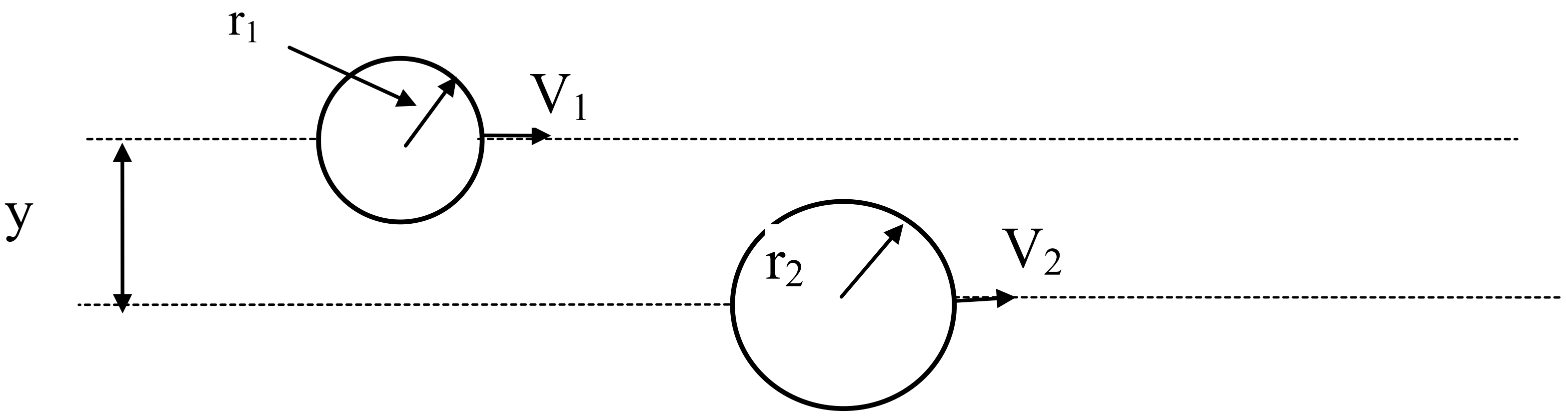

CAR 4568
AFM 4045

------------------<u>FLOCCULATION</u>

- Flocculation forms particles of larger ‘diameter’.
- Flocs grow when particles are colliding with each other and the chemistry of the system enables particles to stick together.
- <u>Perikinetic Flocculation</u> (Brownian motion). Bombardment of colloidal particles by molecules causes collisions. The effect on larger flocs is negligible .

--------------FLOCCULATION

- Orthokinetic Flocculation- Smoluchowski's model. If y < (r1+r2) and V1 > V2 the two particles will collide.



Orthokinetic Flocculation

- The velocity gradient G can be written as:

$$G = \frac{V_1 - V_2}{y}$$

- The velocity gradient must be induced by impellers rotated slowly by electric motors or by frequent changes in direction of the flow

Smoluchowski's model

- The Smoluchowski model leads to the result that the total number of collisions per unit volume in unit time is given by:

$$N = \tfrac{2}{3} n^2 G d^3$$

- where *n* is the number of particles per unit volume
- and *d* is the particle diameter

So the rate of flocculation is proportional to:

- the velocity gradient
- the volume of the sphere of influence of the particles
- the square of the numerical concentration of the particles

DESIGN OF FLOCCULATORS

- Facts:
- Common jar-test equipment gives no information regarding full-scale velocity gradients.
- Typical values of velocity gradient are between 20 to 100 s^{-1}.
- The Camp Number is the product of velocity gradient and detention time, Gt, and reflects the total number of collisions. Typical value are $2x10^4$ to $2x10^5$.

FLOCCULATORS

- Detention times should be greater than 10 minutes.
- The quality of floc produced can be assessed by observing how the floc reflects light.
- The average velocity gradient can be related to the energy dissipated:

$$G = \left(\frac{P}{\mu V} \right)^{1/2}$$

Design

- Power input is given by the following equation:
- $P = F_D V \quad = \frac{1}{2} C_D \rho A V^3$
- P is in watts, F_D is the drag force (mkg/s^2), C_D is the drag coefficient, A is the submerged area of the paddle in square metre, and V is the relative velocity of the paddle in m/s. V is approximated as 0.75 x peripheral velocity of the paddle=1.5πrn, where n is in rps

-------design

- Rotation of the paddle varies from 2 to 15 revolution per minute
- Peripheral velocity of paddle from 0.2 to 0.8 m/s

(i) Hydraulic Flocculator

- The flow is directed around, or over and under, fixed baffles so that the changes in direction produce the required turbulence.
- There are no moving parts.
- they cannot be adjusted to suit varying conditions

-Hydraulic Flocculator

- The rate of energy dissipation is given by the mass flow rate ρg and the head loss h.
- $P=Q\rho gh$
- $$G=\sqrt{\frac{P}{V\mu}}$$

$$\sqrt{\frac{Q\rho gh}{V\mu}}$$

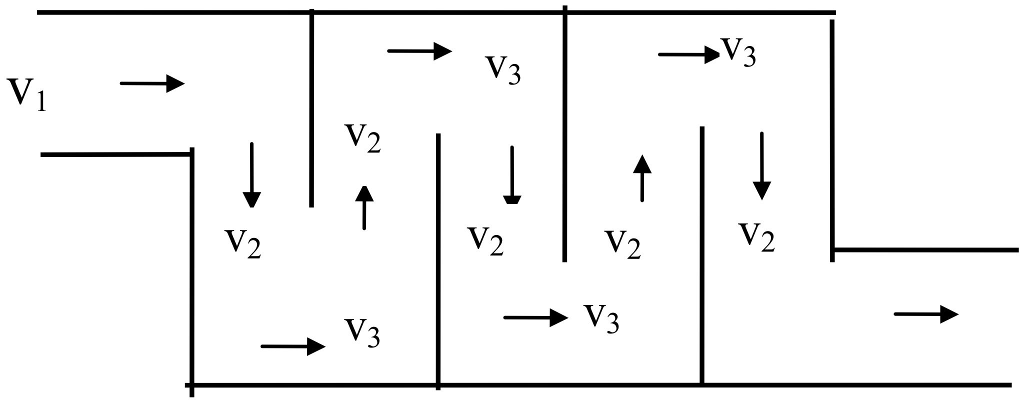
--Hydraulic Flocculator

- For turbulent flow the head loss is approximately proportional to the square of the flow rate (i.e. $h=KQ^2$) so the effect of variations in flow rate can be assessed using:

$$G = \sqrt{\frac{KQ^3 \rho g}{V\mu}}$$

---Hydraulic Flocculator

- The head loss occurring in a baffle flocculator can be estimated by assuming that the kinetic energy is lost at each change in direction.



$$\Delta H = (v_1^2 + 5v_2^2 + 4v_3^2)/2g + \text{normal channel friction}$$

----Hydraulic Flocculator

- Instead of baffle walls, pipes may be used to produce jets.
- The velocities in such flocculators are typically in the range 0.15 to 0.5 m/s

Mechanical Flocculator

- Velocity gradients are caused by the rotation of a paddle about a horizontal shaft or of an impeller about a vertical shaft .
- The paddle tip speed should not exceed 0.6 m/s to prevent excessive local velocity gradients .
- Vertical-shaft systems need no underwater bearings and produce a more uniform distribution of velocity gradients

The mixing effect of the paddle or impeller some of the water may pass through the vessel in a much shorter time,

as illustrated by the table below:

Number of tanks in series	**1**	**3**	**5**
Percentage of the flow that passes through the flocculation stage in less than half of the theoretical detention time	39	20	11

Example: coagulation

- A treatment plant has a capacity of 2 million litres per day. Estimate the Camp number, size of the tank and power input in the coagulation tank based on the following data:
- Retention time = 1.5 minutes
- Velocity gradient, G = 700s^{-1}
- Dynamic viscosity = 0.87×10^{-3} kgm^{-1} s^{-1}

----Answer:

Retention time = 1.5 minutes
Velocity gradient, G = 700s^{-1}
Dynamic viscosity = 0.87x10^{-3} kgm^{-1}s^{-1}
Q = 2 MLD

Camp No =Gt = 700 x 1.5x60 = 63,000
Volume V = Qt = $\frac{2,000}{24x60}x1.5$= 2.08 m^3

Velocity gradient $G = \left(\frac{P}{\mu V}\right)^{1/2}$
Therefore power input , P=G^{2}μV= 700^{2}x0.87x10^{-3} x 2.08 = 886.7 watt

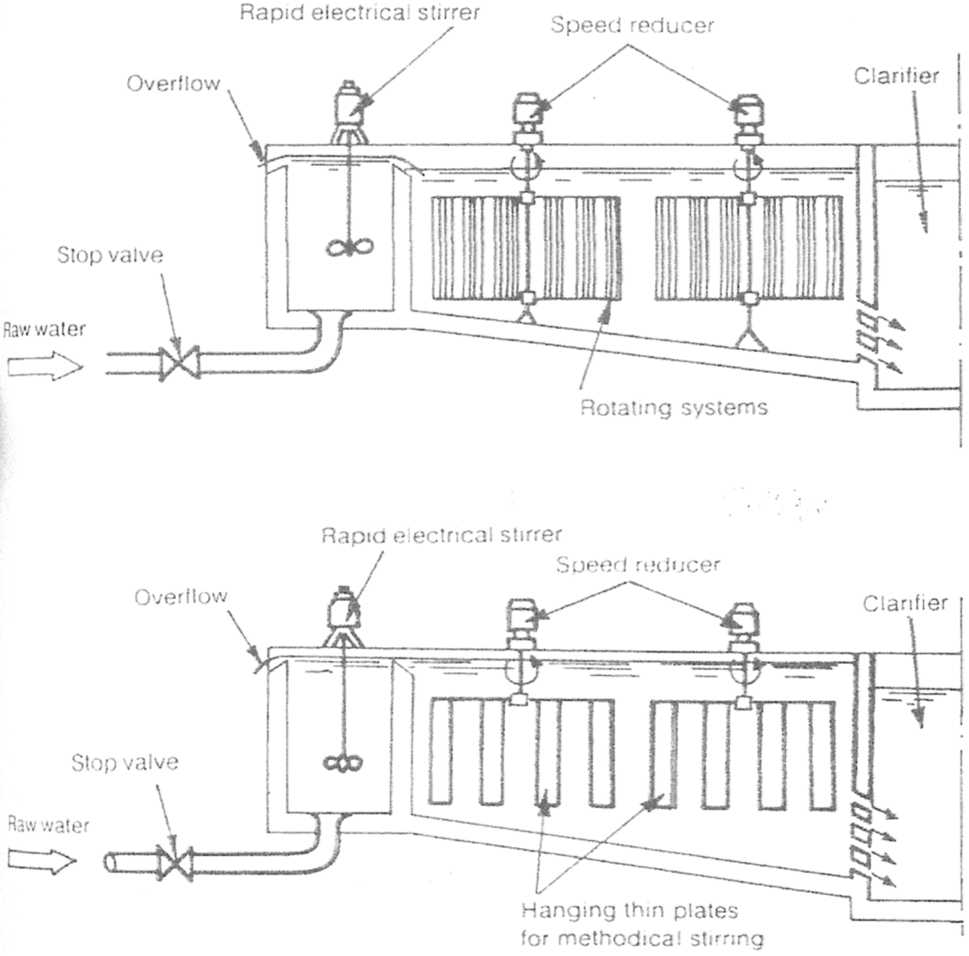


Fig. 5.3. Mechanical flocculators (by courtesy of SA CTE)

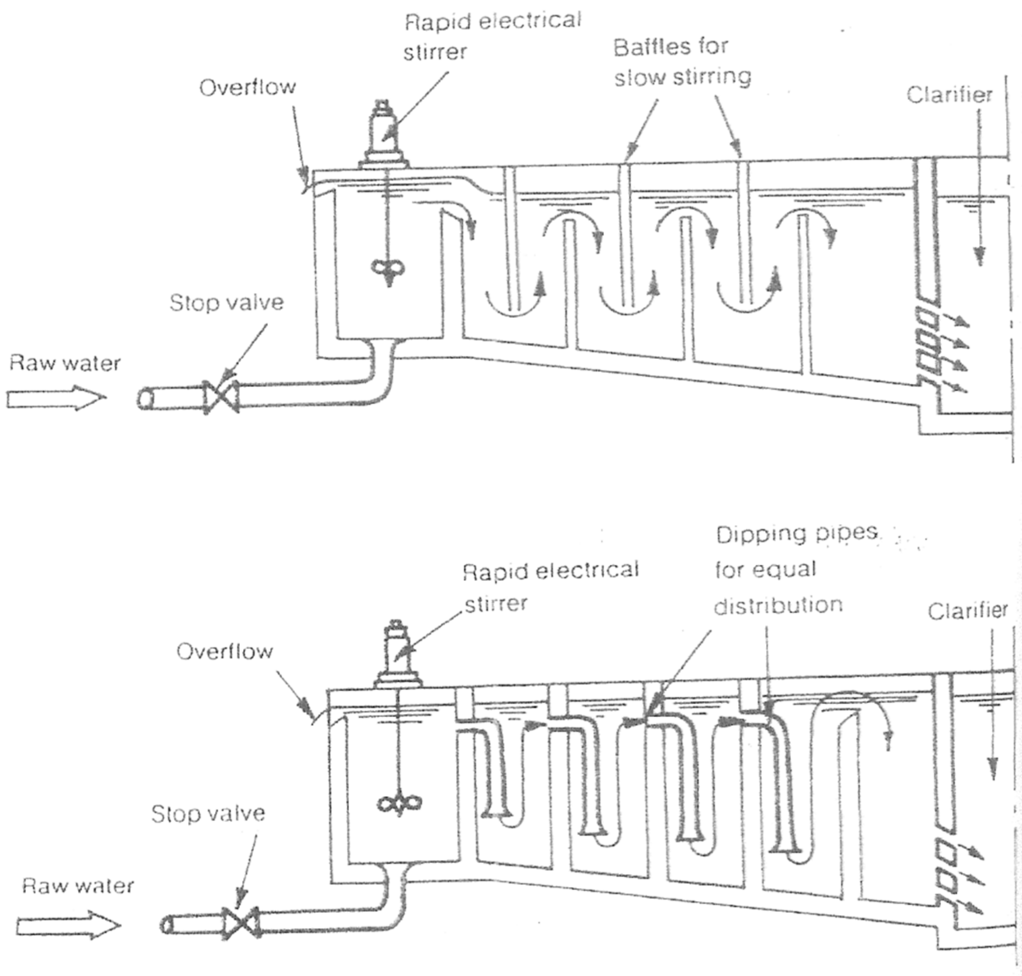


Fig. 5.2. Hydrodynamic flocculators (by courtesy of SA CTE)

Example

- A sinuous channel has 15 round-the-end cross-walls. Water is passed along with a velocity of 0.2m/s between cross-wall and 0.5m/s round the ends. The flow is 0.3m^3/s and the nominal retention time is 25 min. for a temperature of 10^{0}C, estimate the additional loss of head, the power dissipated, velocity gradient and Camp Number.

Properties of saturated water

Temp. T, °C	Saturation Pressure P_{sat}, kPa	Density ρ, kg/m³		Enthalpy of Vaporization h_{fg}, kJ/kg	Specific Heat c_p, J/kg · K		Thermal Conductivity k, W/m · K		Dynamic Viscosity μ, kg/m · s		Prandtl Number Pr		Volume Expansion Coefficient β, 1/K
		Liquid	Vapor		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid
0.01	0.6113	999.8	0.0048	2501	4217	1854	0.561	0.0171	1.792×10^{-3}	0.922×10^{-5}	13.5	1.00	-0.068×10^{-3}
5	0.8721	999.9	0.0068	2490	4205	1857	0.571	0.0173	1.519×10^{-3}	0.934×10^{-5}	11.2	1.00	0.015×10^{-3}
10	1.2276	999.7	0.0094	2478	4194	1862	0.580	0.0176	1.307×10^{-3}	0.946×10^{-5}	9.45	1.00	0.733×10^{-3}
15	1.7051	999.1	0.0128	2466	4186	1863	0.589	0.0179	1.138×10^{-3}	0.959×10^{-5}	8.09	1.00	0.138×10^{-3}
20	2.339	998.0	0.0173	2454	4182	1867	0.598	0.0182	1.002×10^{-3}	0.973×10^{-5}	7.01	1.00	0.195×10^{-3}
25	3.169	997.0	0.0231	2442	4180	1870	0.607	0.0186	0.891×10^{-3}	0.987×10^{-5}	6.14	1.00	0.247×10^{-3}
30	4.246	996.0	0.0304	2431	4178	1875	0.615	0.0189	0.798×10^{-3}	1.001×10^{-5}	5.42	1.00	0.294×10^{-3}
35	5.628	994.0	0.0397	2419	4178	1880	0.623	0.0192	0.720×10^{-3}	1.016×10^{-5}	4.83	1.00	0.337×10^{-3}
40	7.384	992.1	0.0512	2407	4179	1885	0.631	0.0196	0.653×10^{-3}	1.031×10^{-5}	4.32	1.00	0.377×10^{-3}
45	9.593	990.1	0.0655	2395	4180	1892	0.637	0.0200	0.596×10^{-3}	1.046×10^{-5}	3.91	1.00	0.415×10^{-3}
50	12.35	988.1	0.0831	2383	4181	1900	0.644	0.0204	0.547×10^{-3}	1.062×10^{-5}	3.55	1.00	0.451×10^{-3}
55	15.76	985.2	0.1045	2371	4183	1908	0.649	0.0208	0.504×10^{-3}	1.077×10^{-5}	3.25	1.00	0.484×10^{-3}
60	19.94	983.3	0.1304	2359	4185	1916	0.654	0.0212	0.467×10^{-3}	1.093×10^{-5}	2.99	1.00	0.517×10^{-3}
65	25.03	980.4	0.1614	2346	4187	1926	0.659	0.0216	0.433×10^{-3}	1.110×10^{-5}	2.75	1.00	0.548×10^{-3}
70	31.19	977.5	0.1983	2334	4190	1936	0.663	0.0221	0.404×10^{-3}	1.126×10^{-5}	2.55	1.00	0.578×10^{-3}
75	38.58	974.7	0.2421	2321	4193	1948	0.667	0.0225	0.378×10^{-3}	1.142×10^{-5}	2.38	1.00	0.607×10^{-3}
80	47.39	971.8	0.2935	2309	4197	1962	0.670	0.0230	0.355×10^{-3}	1.159×10^{-5}	2.22	1.00	0.653×10^{-3}
85	57.83	968.1	0.3536	2296	4201	1977	0.673	0.0235	0.333×10^{-3}	1.176×10^{-5}	2.08	1.00	0.670×10^{-3}
90	70.14	965.3	0.4235	2283	4206	1993	0.675	0.0240	0.315×10^{-3}	1.193×10^{-5}	1.96	1.00	0.702×10^{-3}
95	84.55	961.5	0.5045	2270	4212	2010	0.677	0.0246	0.297×10^{-3}	1.210×10^{-5}	1.85	1.00	0.716×10^{-3}
100	101.33	957.9	0.5978	2257	4217	2029	0.679	0.0251	0.282×10^{-3}	1.227×10^{-5}	1.75	1.00	0.750×10^{-3}
110	143.27	950.6	0.8263	2230	4229	2071	0.682	0.0262	0.255×10^{-3}	1.261×10^{-5}	1.58	1.00	0.798×10^{-3}
120	198.53	943.4	1.121	2203	4244	2120	0.683	0.0275	0.232×10^{-3}	1.296×10^{-5}	1.44	1.00	0.858×10^{-3}
130	270.1	934.6	1.496	2174	4263	2177	0.684	0.0288	0.213×10^{-3}	1.330×10^{-5}	1.33	1.01	0.913×10^{-3}
140	361.3	921.7	1.965	2145	4286	2244	0.683	0.0301	0.197×10^{-3}	1.365×10^{-5}	1.24	1.02	0.970×10^{-3}
150	475.8	916.6	2.546	2114	4311	2314	0.682	0.0316	0.183×10^{-3}	1.399×10^{-5}	1.16	1.02	1.025×10^{-3}
160	617.8	907.4	3.256	2083	4340	2420	0.680	0.0331	0.170×10^{-3}	1.434×10^{-5}	1.09	1.05	1.145×10^{-3}
170	791.7	897.7	4.119	2050	4370	2490	0.677	0.0347	0.160×10^{-3}	1.468×10^{-5}	1.03	1.05	1.178×10^{-3}
180	1,002.1	887.3	5.153	2015	4410	2590	0.673	0.0364	0.150×10^{-3}	1.502×10^{-5}	0.983	1.07	1.210×10^{-3}
190	1,254.4	876.4	6.388	1979	4460	2710	0.669	0.0382	0.142×10^{-3}	1.537×10^{-5}	0.947	1.09	1.280×10^{-3}
200	1,553.8	864.3	7.852	1941	4500	2840	0.663	0.0401	0.134×10^{-3}	1.571×10^{-5}	0.910	1.11	1.350×10^{-3}
220	2,318	840.3	11.60	1859	4610	3110	0.650	0.0442	0.122×10^{-3}	1.641×10^{-5}	0.865	1.15	1.520×10^{-3}
240	3,344	813.7	16.73	1767	4760	3520	0.632	0.0487	0.111×10^{-3}	1.712×10^{-5}	0.836	1.24	1.720×10^{-3}
260	4,688	783.7	23.69	1663	4970	4070	0.609	0.0540	0.102×10^{-3}	1.788×10^{-5}	0.832	1.35	2.000×10^{-3}
280	6,412	750.8	33.15	1544	5280	4835	0.581	0.0605	0.094×10^{-3}	1.870×10^{-5}	0.854	1.49	2.380×10^{-3}
300	8,581	713.8	46.15	1405	5750	5980	0.548	0.0695	0.086×10^{-3}	1.965×10^{-5}	0.902	1.69	2.950×10^{-3}
320	11,274	667.1	64.57	1239	6540	7900	0.509	0.0836	0.078×10^{-3}	2.084×10^{-5}	1.00	1.97	
340	14,586	610.5	92.62	1028	8240	11,870	0.469	0.110	0.070×10^{-3}	2.255×10^{-5}	1.23	2.43	
360	18,651	528.3	144.0	720	14.690	25,800	0.427	0.178	0.060×10^{-3}	2.571×10^{-5}	2.06	3.73	
374.14	22,090	317.0	317.0	0	—	—	—	—	0.043×10^{-3}	4.313×10^{-5}			

Note 1: Kinematic viscosity ν and thermal diffusivity α can be calculated from their definitions, $\nu = \mu/\rho$ and $\alpha = k/\rho c_p = \nu/\text{Pr}$. The temperatures 0.01°C, 100°C, and 374.14°C are the triple-, boiling-, and critical-point temperatures of water, respectively. The properties listed above (except the vapor density) can be used at any pressure with negligible error except at temperatures near the critical-point value.

Note 2: The unit kJ/kg · °C for specific heat is equivalent to kJ/kg · K, and the unit W/m · °C for thermal conductivity is equivalent to W/m · K.

Source: Viscosity and thermal conductivity data are from J. V. Sengers and J. T. R. Watson, *Journal of Physical and Chemical Reference Data* 15 (1986), pp. 1291–1322. Other data are obtained from various sources or calculated.

Solution

- Additional head loss $\Delta H = (nv_1^2 + (n-1)v_2^2)/2g$
- Where n-1 is the number of baffles
- V_1 is the velocity between the baffles, m/s
- V_2 is the velocity at the baffle slots, m/s
- Therefore additional head loss
- $=(16x0.2^2+15x0.5^2)/2x9.81=0.224m$
- $P=\rho ghQ=1000x9.81x0.224x0.3=659w$
- Vol. = txQ=25x0.3x60=450
- $G=(p/\mu xVol.)^{1/2}=[659/(1.31x10^{-3}x450)]^{1/2}=33.4/s$

Example

- A flocculator is designed to treat 75,000 m^3/day is 30m long, 12m wide and 4.5m deep. It is equipped with 0.3m paddles supported parallel to and moved by 4 horizontal shafts which rotate at a speed of 2.5 rpm. The centre line of the paddle is 1.7m from the shaft, which is at mid depth of the tank. Two paddles are mounted on each shaft, one opposite the other. Assuming that the mean velocity of the water is approximately ¼ the velocity of the paddles, that the drag coefficient of the paddles is 1.8 and that the temperature of water is 10^0C,

- Determine:
- (a) the differential velocity between paddles and the water
- (b) the useful power input and the energy consumption
- (c) the detention time
- (d) the values of G and Gt

Solution

$$P = F_D V = \frac{1}{2} C_D \rho A V^3$$

- P=power input (w), F_D=drag force (mkg/s^2), C_D=drag cofficient, ρ=density (kg/m^3), A=submerged area of the paddles(m^2), V= relative velocity of the paddle (m/s). V may be approximated to 0.75 times the peripheral velocity of the paddle or equals 1.5πrn where r is relative radius of the paddle (m) and n is the no. of revolution per second. Please do the rest!

- Example
- Two sets of jar tests are conducted on raw water containing 30 NTU and an alkalinity concentration of 40 mg/L expressed as $CaCO_3$. Given the data as shown in Table 1, find the optimal pH, coagulant dose and the theoretical amount of alkalinity that would be consumed at the optimal dose.

The reaction occurs when water is added with alum is shown below:

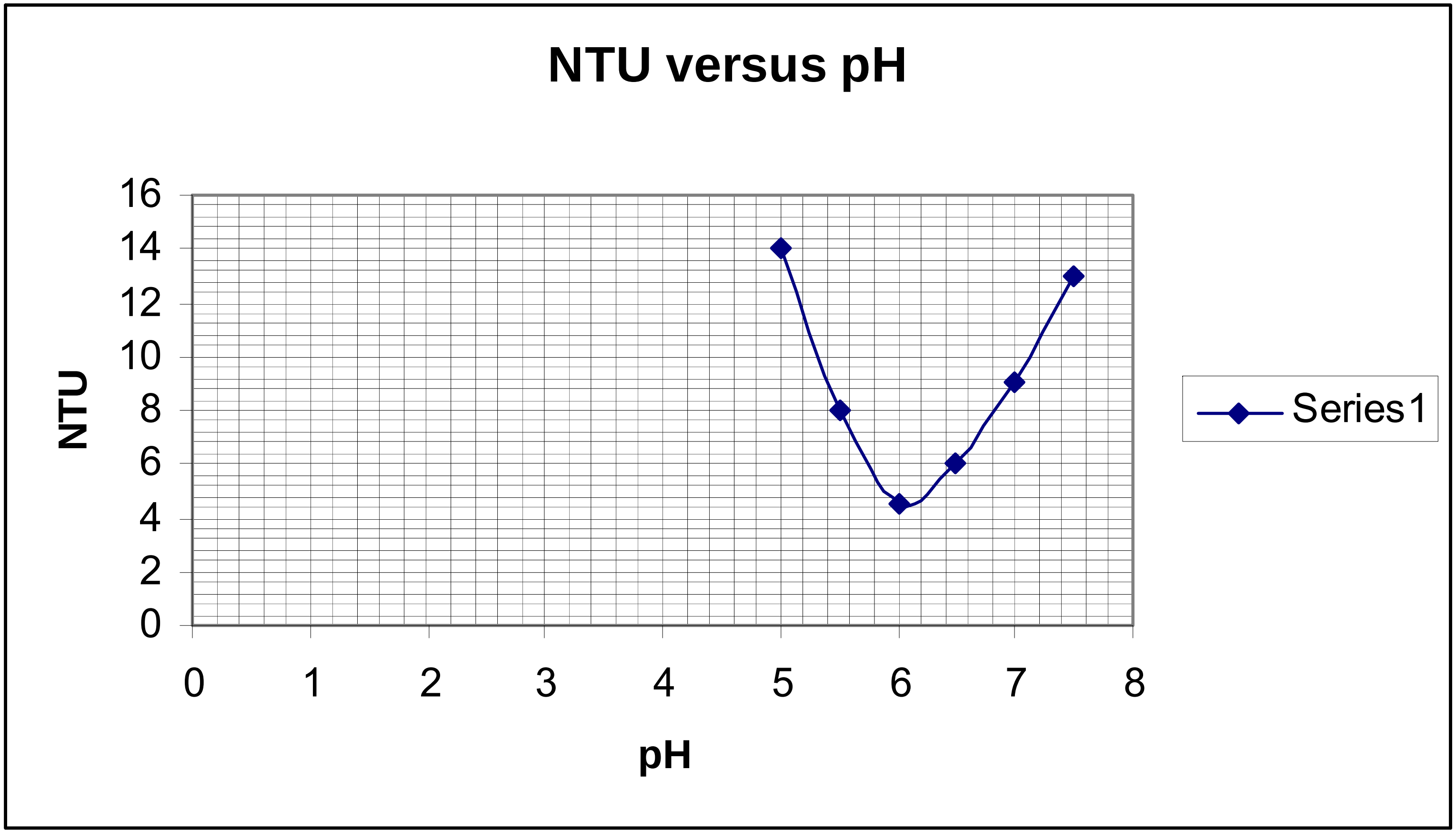
$Al_2(SO_4)_3.14H_2O + 6HCO_3^- \rightarrow 2Al(OH)_3 + 6CO_2 + 14H_2O + 3SO_4^{2-}$

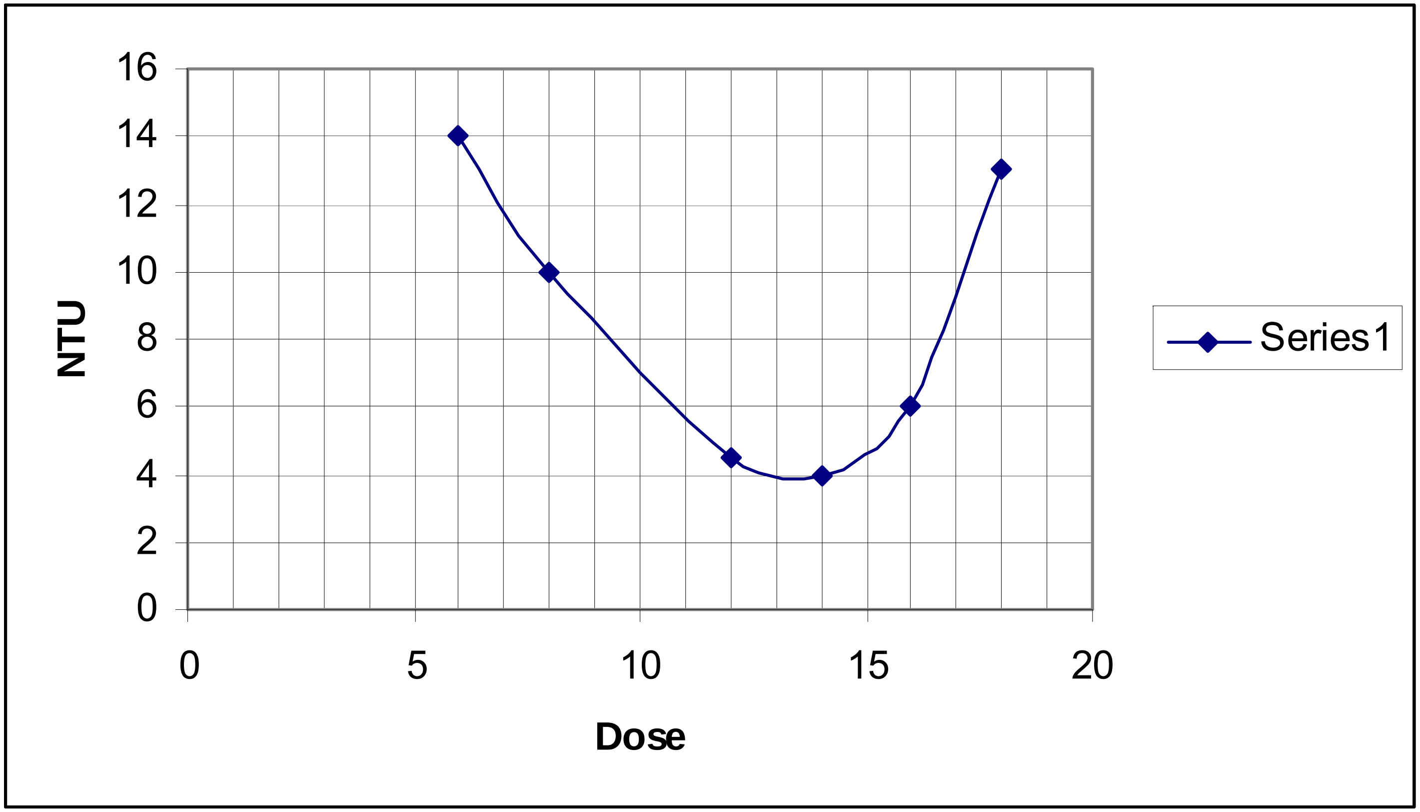
Molecular weights of the elements are shown as follows:

Oxygen = 16, sulphur = 32, aluminium = 27, hydrogen =1 and carbon = 12.

Table 1

<table>
<tr><th colspan="7">Jar Test 1</th></tr>
<tr><td>Jar</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>pH</td><td>5.0</td><td>5.5</td><td>6.0</td><td>6.5</td><td>7.0</td><td>7.5</td></tr>
<tr><td>Alum dose (mg/L)</td><td>15</td><td>15</td><td>15</td><td>15</td><td>15</td><td>15</td></tr>
<tr><td>Turbidity (NTU)</td><td>14</td><td>8</td><td>4.5</td><td>6.0</td><td>9</td><td>13</td></tr>
<tr><th colspan="7">Jar Test 2</th></tr>
<tr><td>Jar</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>pH</td><td>6.0</td><td>6.0</td><td>6.0</td><td>6.0</td><td>6.0</td><td>6.0</td></tr>
<tr><td>Alum dose (mg/L)</td><td>6</td><td>8</td><td>12</td><td>14</td><td>16</td><td>18</td></tr>
<tr><td>Turbidity (NTU)</td><td>14</td><td>10</td><td>4.5</td><td>4.0</td><td>6</td><td>13</td></tr>
</table>


NTU versus pH
16
14
12
10
8
6
4
2
0
NTU
0
1
2
3
4
5
6
7
8
pH
Series1



16
14
12
10
8
6
4
2
0
NTU
0
5
10
15
20
Dose
Series1

The amount of alkalinity used can be obtained from the following equation:

$Al_2(SO_4)_3.14H_2O + 6HCO_3^- \rightarrow 2Al(OH)_3 + 6CO_2 + 14H_2O + 3SO_4^{2-}$

- Where 1 mole of alum used 6 moles of
- MW of alum as follows:
- $Al_2 = 27 \times 2 = 54$
- $S_3 = 32 \times 3 = 96$
- $O_{12} = 16 \times 12 = 192$
- $H_{28} = 1 \times 28 = 28$
- $O_{14} = 16 \times 14 = 224$
- Total = 594

- From the graph optimum dose of alum is **13.5**mg/L
- Molarity or molar is expressed in mg/L by the following expression;
- Mg/L = Molarity x MW x10^3
- =(Mol/L) (g/Mol) (10^3 mg/g)……. (1)
- ∴Mole of alum added per litre =

$$\frac{13.5 \, x \, 10^{-3} \ g/L}{594 \, g/Mol} = 2.27x10^{-5} \ Mol/L.$$

- Where it will consume:
- $6(2.27\text{x}10^{-5}) = \mathbf{1.36x10^{-4}}$ M or molar
- Note: **1 molar solution has 1 mole substance per litre solution**.
-
- Molecular weight = 61 i.e. (1+12+48),
- $\therefore$ from equation (1),
- $(1.36\text{x}10^{-4}$ mol/L) (61 g/mol) $(10^{3}$ mg/g) = 8.31 **mg/L** has been used

This can be expressed in the following equation :

$$\text{mg/L as } CaCO_3 = (\text{mg/L spesis})\left[\frac{\text{EW } CaCO_3}{\text{EW spesis}}\right] \qquad (2)$$

Where EW = equivalent weight

$$\therefore \text{ mg/L as} CaCO_3 = 8.31 x \frac{50}{61} \quad = \mathbf{6.811} \text{ mg/L } HCO_3^- \text{ as } CaCO_3$$

$$\text{Note: EW= equivalent weight} = \frac{\text{molecular weight or atomic}}{n}$$

where in precipitation reaction is the valence of the element in question, in the acid/base reaction, n is the number of hydrogen ionsthat the molecule transfers

Theory for CHEMICAL PRECIPITATION

- Involves the addition of chemicals to alter the physical state of dissolved and suspended solids and to facilitate their removal by sedimentation.
- May result in the net increase in the dissolved constituents in the wastewater.
- Have been developed for the complete secondary treatment of the untreated wastewater including for the removal of nitrogen or phosphorous or both.

Chemical Precipitation for Improving Plant Performance

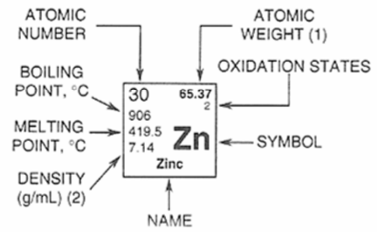
- Was used to enhance the degree of suspended solids and BOD removal.
- Since 1970 chemical precipitation used for more complete removal of organic compounds and nutrients contained in wastewater.

The most common chemicals used are shown in the following table

Chemical	Formula	Molecular weight	Dry Density (lb/ft^3) x 16.0185=kg/m^3	Liquid density (lb/ft^3)
Alum	$Al_2(SO_4)_3.18H_2O$* $Al_2(SO_4)_3.14H_2O$*	666.7 594.3	60-75 60-75	78-80(49%) 83-85(49%)
Ferric chloride	$FeCl_3$	162.1		84-93
Ferric sulphate	$Fe_2 (SO_4)_3.$ $Fe_2(SO_4)_3.3H_2O$	400 454		70-72
Ferrous sulphate (copperas)	$FeSO_4)_3.7H_2O$	278.0	62-66	
Lime	$Ca(OH)_2$	56 as Ca O	35-50	

PERIODIC TABLE OF THE ELEMENTS

(Modified from a table published and copyrighted by Sargent-Welch Scientific Company, Skokie, Illinois, and used with their permission)



NOTES:

(1) Atomic weights are 1971 values. Parentheses indicated most stable or best known isotope.

(2) Density values for gaseous elements are for liquids at the boiling point.

(3) Names and symbols for elements 104 and 105 are proposed but not yet officially accepted.

Group IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII	VIII	VIII	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 1.0079 1 −252.7 −259.2 0.071 **H** Hydrogen																	2 4.0026 −268. 9 −269.7 0.126 **He** Helium
3 6.939 1 1330 180.5 0.53 **Li** Lithium	4 9.0122 2 2770 1277 1.85 **Be** Beryllium											5 10.811 3 – (2030) 2.34 **B** Boron	6 12.01115 ±4,2 4830 3727 2.26 **C** Carbon	7 14.0067 ±3,5,4,2 −195.8 −210 0.81 **N** Nitrogen	8 15.9994 −2 −183 −218.8 1.14 **O** Oxygen	9 18.9984 −1 −188.2 −219.6 1.505 **F** Fluorine	10 20.183 −246 −248.6 1.20 **Ne** Neon
11 22.9898 1 892 97.8 0.97 **Na** Sodium	12 24.312 2 1107 650 1.74 **Mg** Magnesium											13 26.9815 3 2450 660 2.70 **Al** Aluminum	14 28.086 4 2680 1410 2.33 **Si** Silicon	15 30.9738 ±3,5,4 280 44.2 1.82 **P** Phosphorus	16 32.064 ±2,4,6 444.6 119.0 2.07 **S** Sulfur	17 35.453 ±1,3,5,7 −34.7 −101.0 1.56 **Cl** Chlorine	18 39.948 −185.8 −189.4 1.40 **Ar** Argon
19 39.098 1 760 63.7 0.86 **K** Potassium	20 40.08 2 1440 838 1.55 **Ca** Calcium	21 44.956 3 2730 1539 3.0 **Sc** Scandium	22 47.90 4,3 3260 1668 4.51 **Ti** Titanium	23 50.942 5,4,3,2 3450 1900 6.1 **V** Vanadium	24 51.996 6,3,2 2665 1875 7.19 **Cr** Chromium	25 54.938 7,6,4,2,3 2150 1245 7.43 **Mn** Manganese	26 55.847 2,3 3000 1536 7.86 **Fe** Iron	27 58.933 2,3 2900 1495 8.9 **Co** Cobalt	28 58.71 2,3 2730 1453 8.9 **Ni** Nickel	29 63.54 2,1 2595 1083 8.96 **Cu** Copper	30 65.38 2 906 419.5 7.14 **Zn** Zinc	31 69.72 3 2237 29.8 5.91 **Ga** Gallium	32 72.59 4 2830 937.4 5.32 **Ge** Germanium	33 74.922 ±3,5 613 817 5.72 **As** Arsenic	34 78.96 −2,4,6 685 217 4.79 **Se** Selenium	35 79.909 ±1,5 58 −7.2 3.12 **Br** Bromine	36 83.80 −152 −157.3 2.6 **Kr** Krypton
37 85.47 1 688 38.9 1.53 **Rb** Rubidium	38 87.62 2 1380 768 2.6 **Sr** Strontium	39 88.905 3 2927 1509 4.47 **Y** Yttrium	40 91.22 4 3580 1852 6.49 **Zr** Zirconium	41 92.906 5,3 3300 2468 8.4 **Nb** Niobium	42 95.94 6,5,4,3,2 5560 2610 10.2 **Mo** Molybdenum	43 (98) 7 – 2140 11.5 **Tc** Technetium	44 101.07 2,3,4 4900 2500 12.2 **Ru** Ruthenium	45 102.905 2,3,4,6,8 4500 1966 12.4 **Rh** Rhodium	46 106.4 2,4 3980 1552 12.0 **Pd** Palladium	47 107.870 1 2210 960.8 10.5 **Ag** Silver	48 112.40 2 765 320.9 8.65 **Cd** Cadmium	49 114.82 3 2000 156.2 7.31 **In** Indium	50 118.69 4,2 2270 231.9 7.30 **Sn** Tin	51 121.75 ±3,5 1380 630.5 6.62 **Sb** Antimony	52 127.60 −2,4,6 989.8 449.5 6.24 **Te** Tellurium	53 126.904 ±1,5,7 183 113.7 4.94 **I** Iodine	54 131.30 −108.0 −111.9 3.06 **Xe** Xenon
55 132.9054 1 690 28.7 1.90 **Cs** Cesium	56 137.34 2 1640 714 3.5 **Ba** Barium	57 138.91 3 3470 920 6.17 **La** ★ Lanthanum	72 178.49 4 5400 2222 13.1 **Hf** Hafnium	73 180.948 5 5425 2996 16.6 **Ta** Tantalum	74 183.85 6,5,4,3,2 5930 3410 19.3 **W** Wolfram	75 186.2 7,6,4,2,−1 5900 3180 21.0 **Re** Rhenium	76 190.2 2,3,4,6,8 5500 3000 22.6 **Os** Osmium	77 192.2 2,3,4,6 5300 2454 22.5 **Ir** Iridium	78 195.09 2,4 4530 1769 21.4 **Pt** Platinum	79 196.967 3,1 2970 1063 19.3 **Au** Gold	80 200.59 2,1 357 −38.4 13.6 **Hg** Mercury	81 204.37 3,1 1457 303 11.85 **Tl** Thallium	82 207.19 4,2 1725 327.4 11.4 **Pb** Lead	83 208.980 3,5 1560 271.3 9.8 **Bi** Bismuth	84 (210) 2,4 – 254 (9.2) **Po** Polonium	85 (210) ±1,3,5,7 – (302) – **At** Astatine	86 (222) (−61.8) (−71) – **Rn** Radon
87 (223) 1 — (27) — **Fr** Francium	88 (226) 2 — 700 5.0 **Ra** Radium	89 (227) 3 — 1050 — **Ac** ★★ Actinium	104 — — — — — **[Rf]** **[Ku]** (Rutherfordium) (Kurchatovium)	105 — — — — — **Ha** Hahnium													

★	58 140.12 3,4 3468 795 6.67 **Ce** Cerium	59 140.907 3,4 3127 935 6.77 **Pr** Praseodymium	60 144.24 3 3027 1024 7.00 **Nd** Neodymium	61 (147) 3 – (1027) – **Pm** Promethium	62 150.35 3,2 1900 1072 7.54 **Sm** Samarium	63 151.96 3,2 1439 826 5.26 **Eu** Europium	64 157.25 3 3000 1312 7.89 **Gd** Gadolinium	65 158.924 3,4 2800 1356 8.27 **Tb** Terbium	66 162.50 3 2600 1407 8.54 **Dy** Dysprosium	67 164.930 3 2600 1461 8.80 **Ho** Holmium	68 167.26 3 2900 1497 9.05 **Er** Erbium	69 168.934 3 1727 1545 9.33 **Tm** Thulium	70 173.04 3,2 1427 824 6.98 **Yb** Ytterbium	71 174.97 3 3327 1652 9.84 **Lu** Lutetium
★★	90 232.04 4 3850 1750 11.7 **Th** Thorium	91 (231) 5,4 – (1230) 15.4 **Pa** Protactinium	92 238.036 6,5,4,3 3818 1132 19.07 **U** Uranium	93 (237) 6,5,4,3 – 637 19.5 **Np** Neptunium	94 (242) 6,5,4,3 3235 640 – **Pu** Plutonium	95 (243) 6,5,4,3 – – 11.7 **Am** Americium	96 (247) 3 – – – **Cm** Curium	97 (247) 4,3 – – – **Bk** Berkelium	98 (249) 3 – – – **Cf** Californium	99 (254) – – – – **Es** Einsteinium	100 (253) – – – – **Fm** Fermium	101 (256) – – – – **Md** Mendelevium	102 (254) – – – **No** Nobelium	103 (257) – – – – **Lr** Lawrencium

CHEMICAL PRECIPITATION

- Degree of clarification obtained depends on the amount of chemical used.
- From 80 to 90% of total suspended matter, 40 to 70% of BOD5, 30 to 60% of COD, and 80 to 90% of the bacteria can be removed.
- Plain sedimentation can only removed 50 to 70% total suspended matter and 30 to 40% organic mater.

Alum

- When alum is added to wastewater containing calcium and magnesium bicarbonate alkalinity the reaction occurs may be illustrated as follows:

$$Al_2\,(SO_4)_3.18H_2O + 3Ca\,(HCO_3)_2 \Leftrightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2 + 18H_2O$$

Alum

$$Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 \Leftrightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2 + 18H_2O \qquad (1)$$

- i.e.
- Aluminium sulphate (666.7) + calcium bicarbonate (3x100 as CaCO3)⇔ calcium sulphate (3x136)+aluminium hydroxide (2x78) +carbon dioxide(6x44) + water (18x18).
- The insoluble aluminium hydroxide is a gelatinous floc that settles slowly through the wastewater.

Alum

- Because alkalinity is reported as CaCO3 , the molecular weight of which is 100, the quantity of alkalinity required to react with 10 mg/L of alum is:

$$10.0\ \text{mg/L}x \frac{3\ \text{x}\ 100\text{g/mol}}{666.7\ \text{g/mol}} = 4.5\ \text{mg/L}$$

- If less than this amount of alkalinity then lime is added but seldom required in the chemical treatment of wastewater.

Ferric chloride

The reactions for ferric chloride are:

162.1 $Fecl_3$	3x18 $+3H_2O \Leftrightarrow$	106.9 $Fe(OH)_3$	$+3H^+$	$+3Cl^-$ (2)
Ferric Chloride	water	Ferric hydroxide		
$3H^+$	$+3HCO_3^- \Leftrightarrow$ bicarbonate	$3H_2CO_3$ carbonic acid		

Ferric sulphate and lime

400	3x56 as Ca O		408		2x106.9	
$Fe_2(SO_4)_3$	$+3Ca(OH)_2$	$\Leftrightarrow$	$3CaSO_4$	+	$2Fe(OH)_3$	(3)
Ferric sulphate	Calcium hydroxide		Calcium sulphate		Ferric hydroxide	

Ferrous sulphate and Lime

- In most cases ferrous sulphate cannot be used alone as a precipitant because lime must be added at the same time to form a precipitate.

The reaction of ferrous sulphate alone is shown below:

278		100 as $CaCO_3$		178		136		7x18	
$FeSO_4.7H_2O$	+	$Ca(HCO_3)_2$	$\Leftrightarrow$	$Fe(HCO_3)_2$	+	$CaSO_4$	+	$7H_2O$	(4)
Ferrous sulphate		Calcium bicarbonate		Ferrous bicarbonate		Calcium sulphate			

If lime in the form of Ca (OH)2 is now added, the reaction:

$$\underset{\text{Ferrous bicarbonate}}{\overset{178}{\mathrm{Fe(HCO_3)_2}}} + \underset{\text{Calcium hydroxide}}{\overset{\text{2x56 as Ca O}}{\mathrm{2Ca(OH)_2}}} \Leftrightarrow \underset{\text{Ferrous hydroxide}}{\overset{89.9}{\mathrm{Fe(OH)_2}}} + \underset{\text{Calcium carbonate}}{\overset{\text{2x100}}{\mathrm{2CaCO_3}}} + \overset{\text{2x18}}{\mathrm{2H_2O}} \qquad (5)$$

Ferrous hydroxide is next oxidised to ferric hydroxide, the final form desired, by oxygen dissolved in the waste water:

4x89.9		32		2x18		4x106.9	
$4Fe(OH)_2$	+	O_2	+	$2H_2O$	⇔	$4Fe(OH)_3$	(6)
Ferrous hydroxide		Oxygen				Ferric hydroxide	

The insoluble ferric is formed as a bulky, gelatinous floc similar to the alum floc.

The alkalinity required for a 10 mg/L dosage ferrous sulphate is

$$10.0\ \text{mg/L x}\ \frac{100\ \text{g/mole}}{278\ \text{g/mole}} = 3.6\ \text{mg/L}$$

Lime required is $$10.0\ \text{mg/L x}\ \frac{2\ \text{x}\ 56\ \text{g/mole}}{278\ \text{g/mole}} = 4.0\ \text{mg/L}$$

The oxygen required is $$10.0\ \text{mg/L} = \frac{32\ \text{g/mole}}{4\ \text{x}\ 278\ \text{g/mole}} = 0.29\ \text{mg/L}$$

Ferrous sulphate and Lime

- Because the formation of ferric hydroxide is dependent on the presence of dissolved oxygen, the reaction in equation 6 cannot be completed with septic waste water or industrial wastes.
- Ferric sulphate may take the place of ferrous sulphate, and its use often avoids the addition of lime and the requirement of dissolved oxygen.

Ferric chloride and Lime

The reactions for ferric chloride and lime are:

2x162		3x56 as Ca O		3x111		2x106.9	
$Fe_2 Cl_3$	+	$3Ca(OH)_2$	$\Leftrightarrow$	$3CaCl_2$	+	$2Fe(OH)_3$	(7)
Ferric chloride		Calcium hydroxide		Calcium sulphate		Ferric hydroxide	

Chemical Precipitation for Phosphate Removal

- Removal of phosphorous from wastewater involves the incorporation of phosphate into the suspended solids and the subsequent removal of those solids.
- Phosphorous can be incorporated into biological or chemical precipitates.
- Metal salts such as alum and ferric chloride are commonly used for the removal.
- Polymers have been also used in conjunction with iron salts and alum.

Chemical Precipitation for Phosphate Removal

- Lime is rarely used due to the problem of substantial increase in the mass of the sludge compared with metal salts. The problems are operating and maintenance associated with handling, storage and feeding of lime.
- Ferrous sulphate and ferrous chloride are also used.
- The precipitation of phosphorous from wastewater can occur in a number of different locations within the following process flow diagram.

Chemistry of Phosphate Removal:

- The quantity of lime required will depend primarily on the alkalinity of the wastewater.
- The quantity of lime required to precipitate the phosphorus in wastewater is typically about 1.4 to 1.5 times the total alkalinity expressed as CaCO3.
- High pH value is required to precipitate phosphate, co-precipitation is usually not feasible.
- Re-carbonation with carbon dioxide (CO2) is used to lower the pH value.

SENDIMENTATION BASIN

- **Sedimentation** – the removal of solids particles from a suspension by settling under gravity.
- **Clarification** – is a similar term which refers specifically to the function of a sedimentation tank in removing suspended matter from the water to give a clarified effluent.

- **Thickening** – the settled impurities are concentrated & compacted on the floors of the tank & in the sludge-collecting hoppers.
- **Sludge** – concentrated impurities withdrawn from the bottom of sedimentation tanks.
- **Scum** – material that floats to the top of the tank.

Application of Sedimentation

- **In water treatment** – to remove impurities that have been rendered settleable by coagulation and flocculation.
- **In municipal wastewater treatment:**
- main process in primary treatment.
- for removing 50 to 70% of the suspended solids.
- to remove the biological flocs produced by micro-organisms after biological treatment.

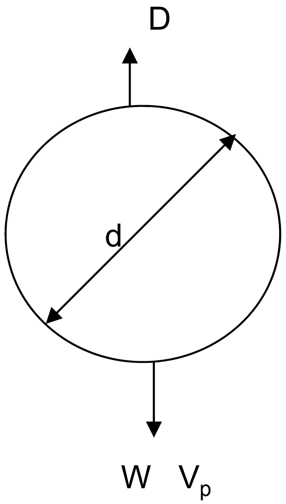
Classification of Settling Behaviour:

- is distinguished on the basis of the nature of particles to be removed and their concentration.
- Class I – unhindered settling of discrete particles.
- Class II – settling of dilute suspensions of flocculent particles.
- Class III – hindered settling & zone settling.
- Class IV – compression settling (compaction).

Ideal Settling Behaviour – Sedimentation Class I

- involving discrete particles.
- Each particles settles freely without interference from adjacent particles.
- As a particle settles, it accelerates until the drag force due to its motion is equal to the submerged weight of the particle. At this juncture the particle will have reached its terminal velocity Vp. Thus gravitational force= drag force

- Settling Particles:
- Density, D = ρ_p
- Volume = $\forall_p$
- Projected Area = A_p
- Vp = settling velocity
- W = submerged wt.
- The drag force on a particle:



- $$D = C_D \rho_f A_p \frac{V_p^2}{2} \qquad (1)$$

Submerged weight of the particle:

$$W = \left(\rho_p - \rho_f\right) g \forall_p \quad \rule{6cm}{0.4pt} \tag{2}$$

Where ρ_f = fluid density

By equating the above expression and after substituting for A_p & $\forall p$;

$$V_p = \sqrt{\frac{4}{3} \frac{\left(\rho_p - \rho_f\right)}{\rho_f} \frac{gd}{C_D}} \quad \rule{6cm}{0.4pt} \tag{3}$$

In practice C_D is a function of Reynolds Number, R_e.

For spherical particles, it can be represented by the following eqn:

For Re<1, $C_D = \frac{24}{R_e}$

For 1<Re<10^4, $C_D = \frac{24}{R_e^{1/2}} + 0.34$

For 10^3<Re<10^5, $C_D \approx 0.4$

Substituting equation (3) for Re<1, where $R_e = \frac{\rho_f V_p d}{\mu}$,

$$\therefore V_p = \frac{g}{18} \frac{(\rho - \rho_f)}{\mu} d^2 \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_}(4)$$

This is known as Stoke’s Law.

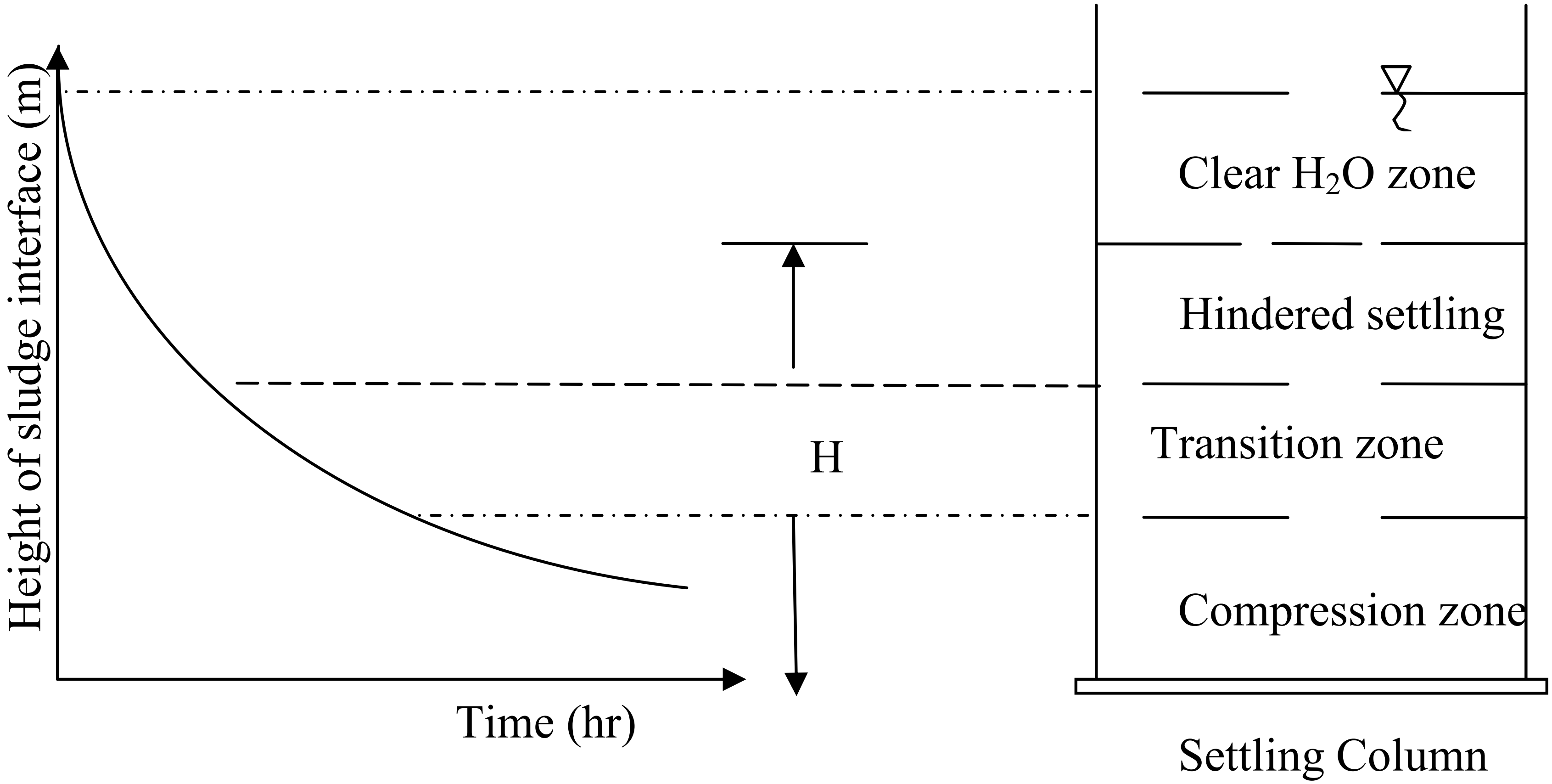
In reality particle diameter & density not normally known.
Particles also have irregular shape

Sendimentation Class II – Settlement of dilute suspensions of flocculation particles.

- involves a variety of particle sizes settling at different rates.
- colliding particles may coalesce to form larger aggregates with an increase settling velocity, so typical path followed by flocculent particles is curved.
- the depth should be great enough to provide the opportunity for particle agglomeration to occur.
- effects of depth & detention time on solids concentration for flocculating particles can be determined by settling tests.

Sendimentation Class III – Hindered settling and sludge blanket clarifiers.

- As the concentration of particles in suspension increased, a point is reached where particles are so close together that they no longer settle independently of one another.
- The velocity fields of the fluid displaced by settling particles
- When particles concentration is so high, the whole suspension tends to settle as a ‘blanket’. This is termed as zone settling. E.g. activated sludge.


Height of sludge interface (m)
Time (hr)
H
Clear H_2O zone
Hindered settling
Transition zone
Compression zone
Settling Column

Sedimentation Class IV – Compression settling.

- As the settling particles approach the floor of the sedimentation tank, particles concentration are very high and are in contact with adjacent particles.
- Settling can only occur by adjustments within the matrix and takes place at a reducing matrix.
- Occurs as the settled solids are compressed under the weighr of overlying solids; voids are gradually diminished.
- E.g. activated sludge final settling tank.

Design Procedures:

- Determine flow rate, Q.
- Select surface loading, $V_S = \frac{Q}{A} = \frac{Q}{BL}$
- For detention time, $t = \frac{LBD}{Q} = \frac{D}{V_S} = \frac{L}{Q/BD}$
- For depth D; $D = V_S.t = V_S \cdot \frac{LBD}{Q}$

- For rectangular tank in practice length: breaddth ratio normally 4:1 or 3:1.

Guidelines for surface loading.

Types of Installation	Surface Loading (m/day)	Detention time (hr)
Small	20 to 30	3 to 4
New Technologies	30 to 40	2½ to 3½
New Tech. + good operation	35 to 45	2 to 3
Large + excellent operation	40 to 60	1½ to 2½

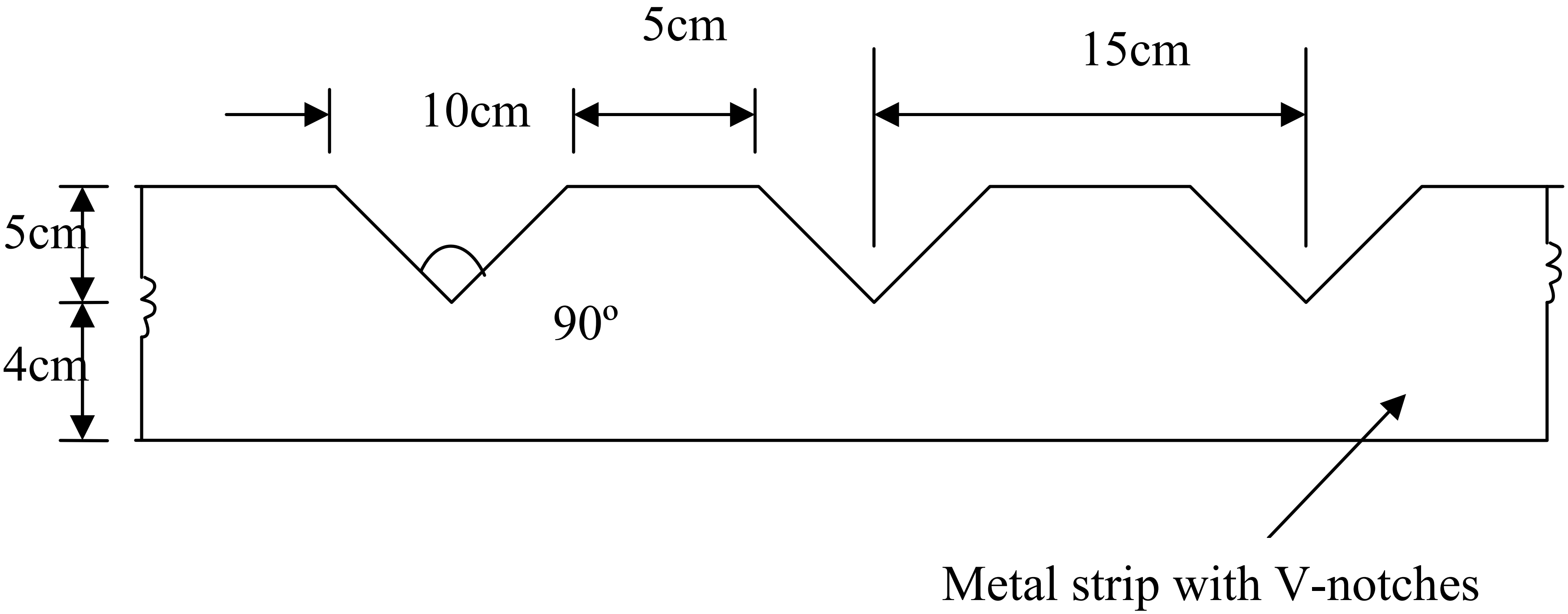
Outlet Arrangement

- IRC Technical Report No.18(1981) suggested:

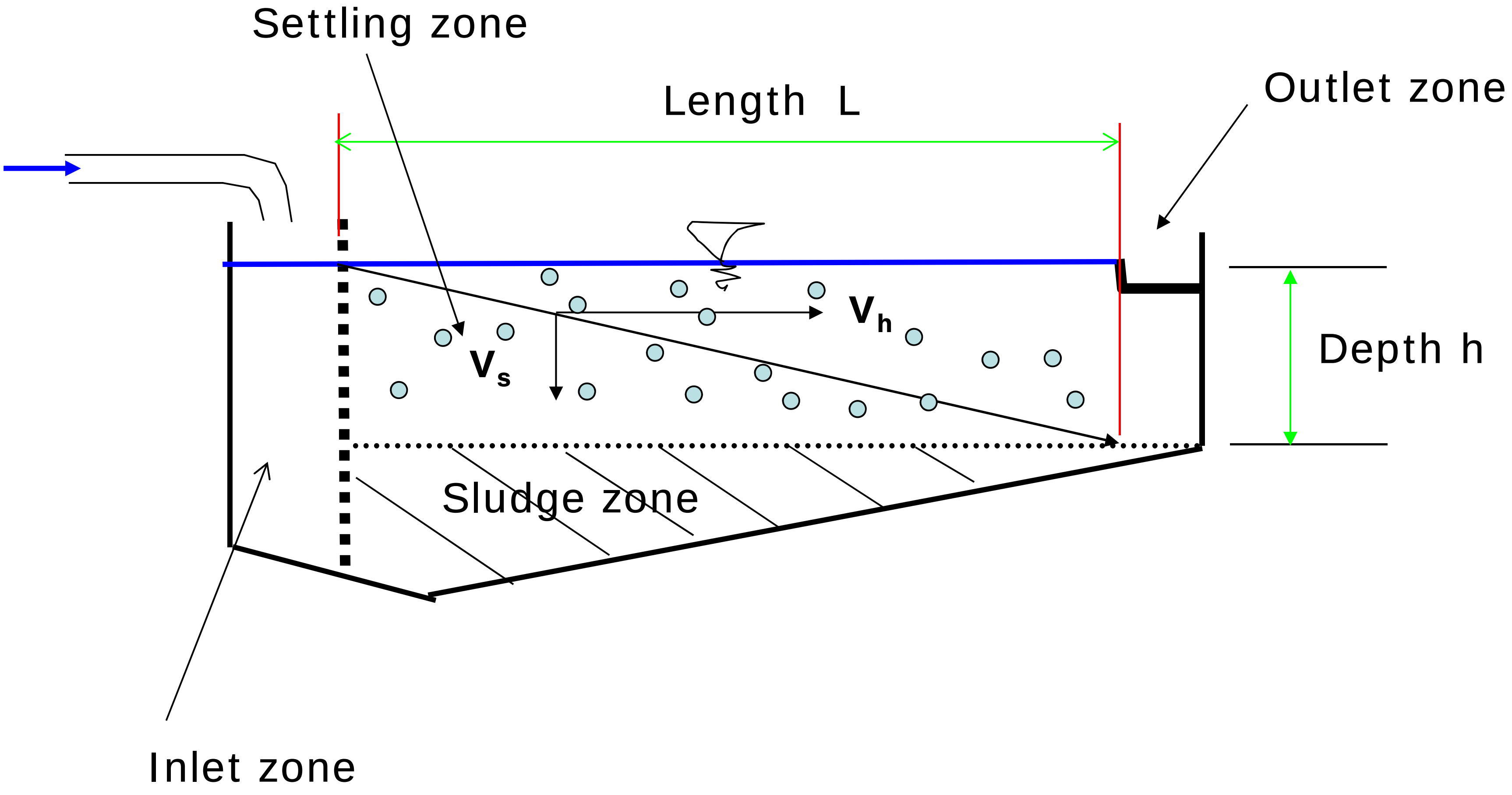
$$L = 0.2Q/HV_s$$

Where:
L = combined weir length (m)
Q = flow rate (m^2/day)
H = depth of tank (m)
V_s = settling velocity (m/day)

Adjustable V-notched weirs are convenient to ensure uniform flow throughout the collecting trough, especially low overflow rates are used



Sedimentation tank



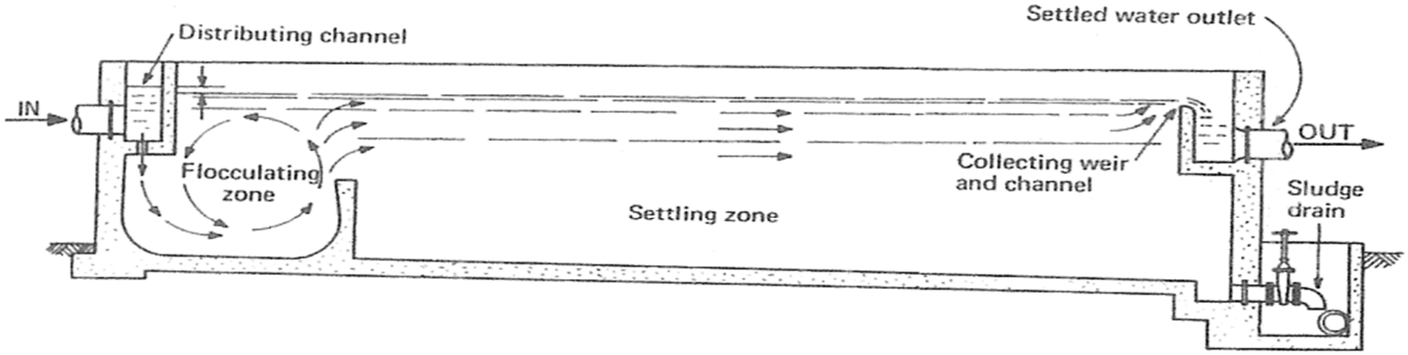


Fig 13.4 An early type of rectangular flocculation and settling unit featuring hydraulic flocculation, horizontal flow sedimentation and intermittent sludge removal from an emptied tank

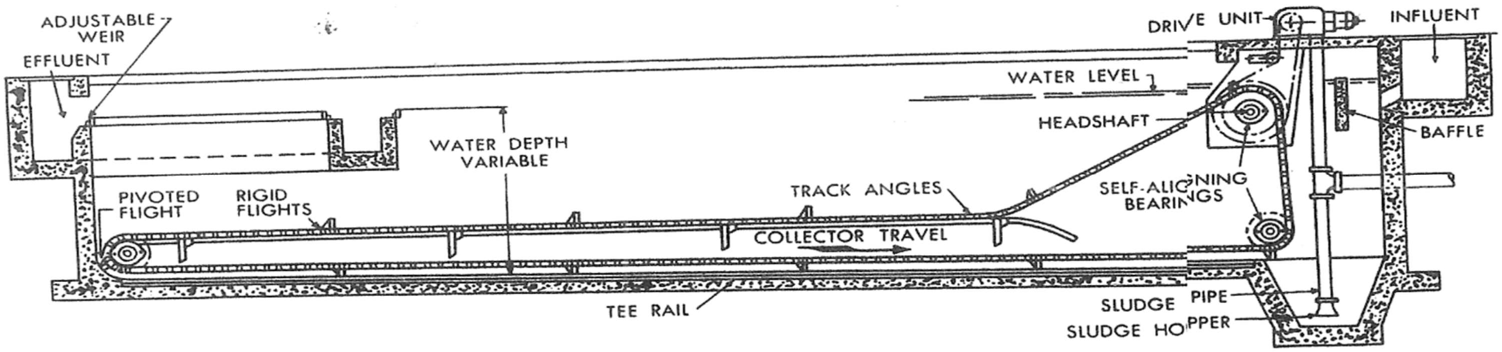
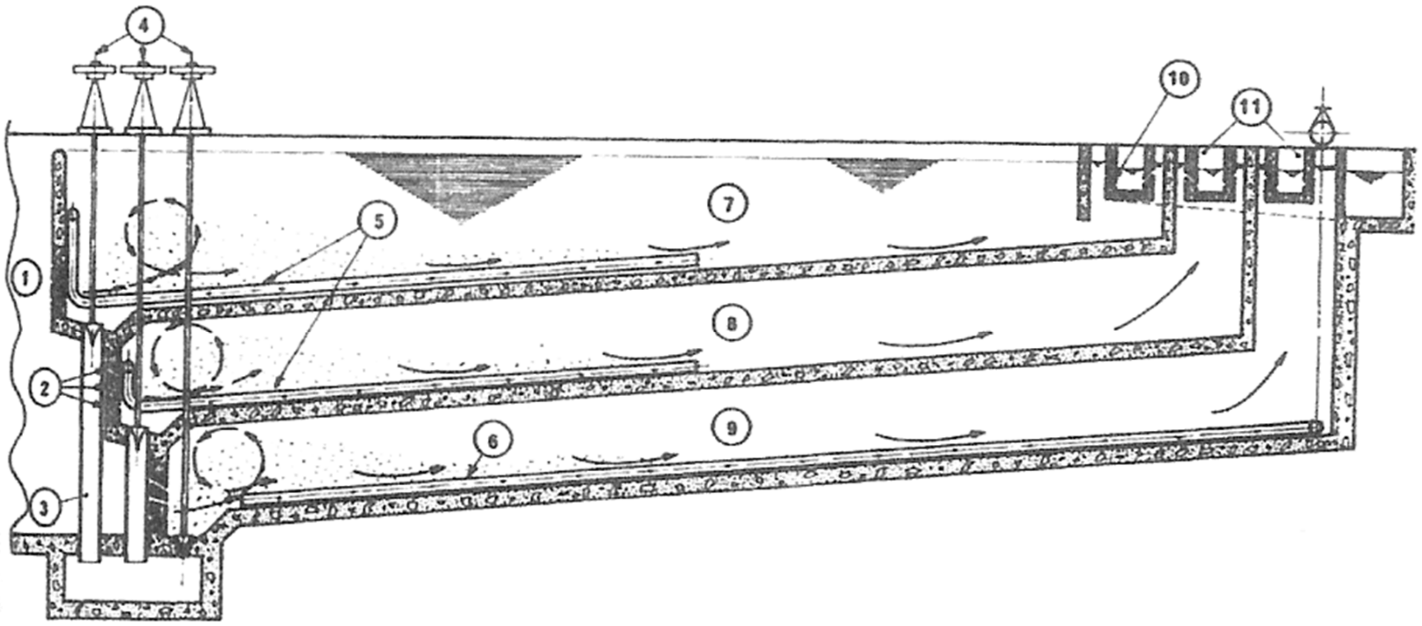


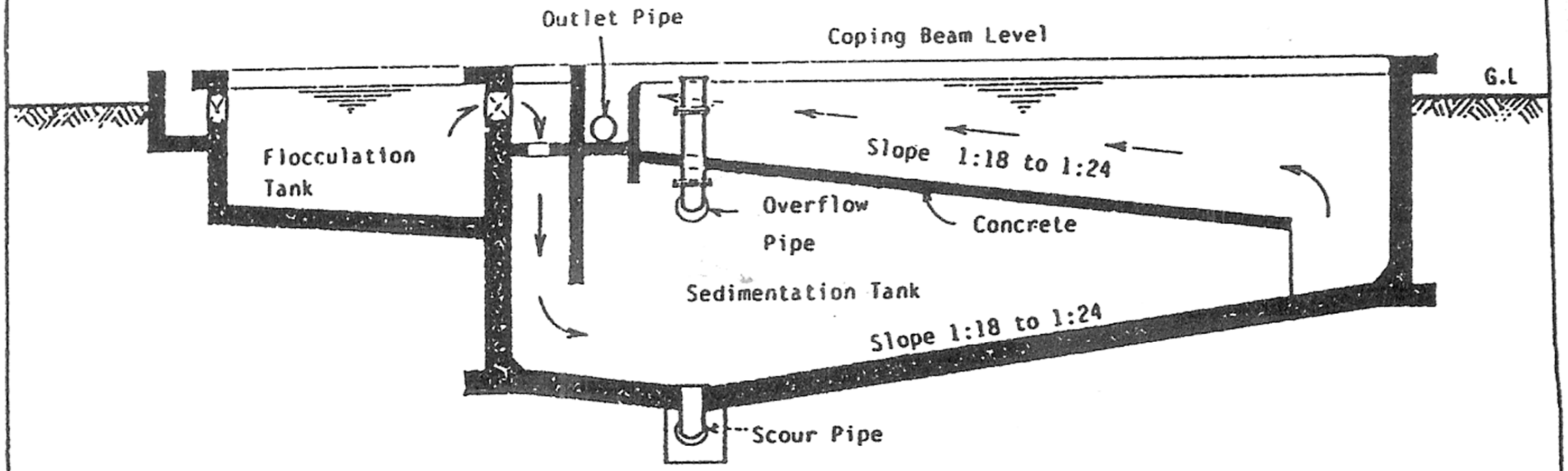
FIGURE 9-12
Rectangular clarifier. (*Courtesy Envirex, a Rexnord Company.*)

Multi-storey horizontal tank

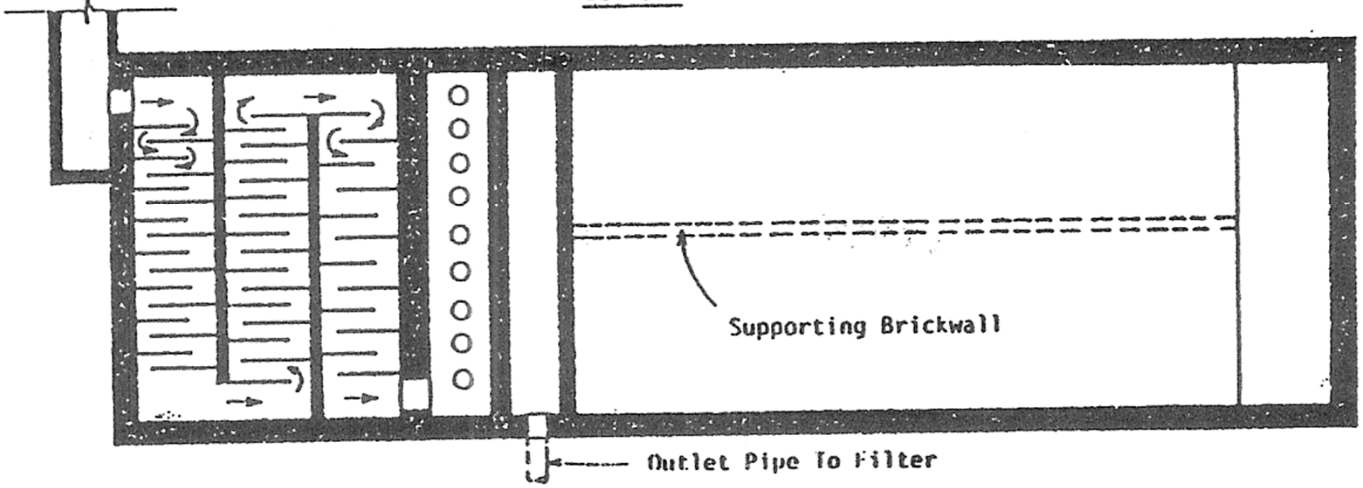


① Flocculation tank
② SPLIT-ROLL inlets
③ Upper floor sludge drain
④ Manually controlled TOP VALVE
⑤ COMBCET: Sludge suction system (optional)
⑥ WATERINSE: Water flushing system (optional)
⑦ Upper clarifying compartment
⑧ Intermediate clarifying compartment
⑨ Lower clarifying compartment
⑩ DUCK-LIPS: Effluent collectors
⑪ Clarified water collecting channels

FIGURE 7.18 Multistory horizontal tank with parallel flow on three levels. (*Source:* Courtesy of OTV, Paris, France, and Kubota Construction Co., Ltd., Tokyo, Japan.)



SECTION



PLAN

Radial flow circular Sedimentation tank

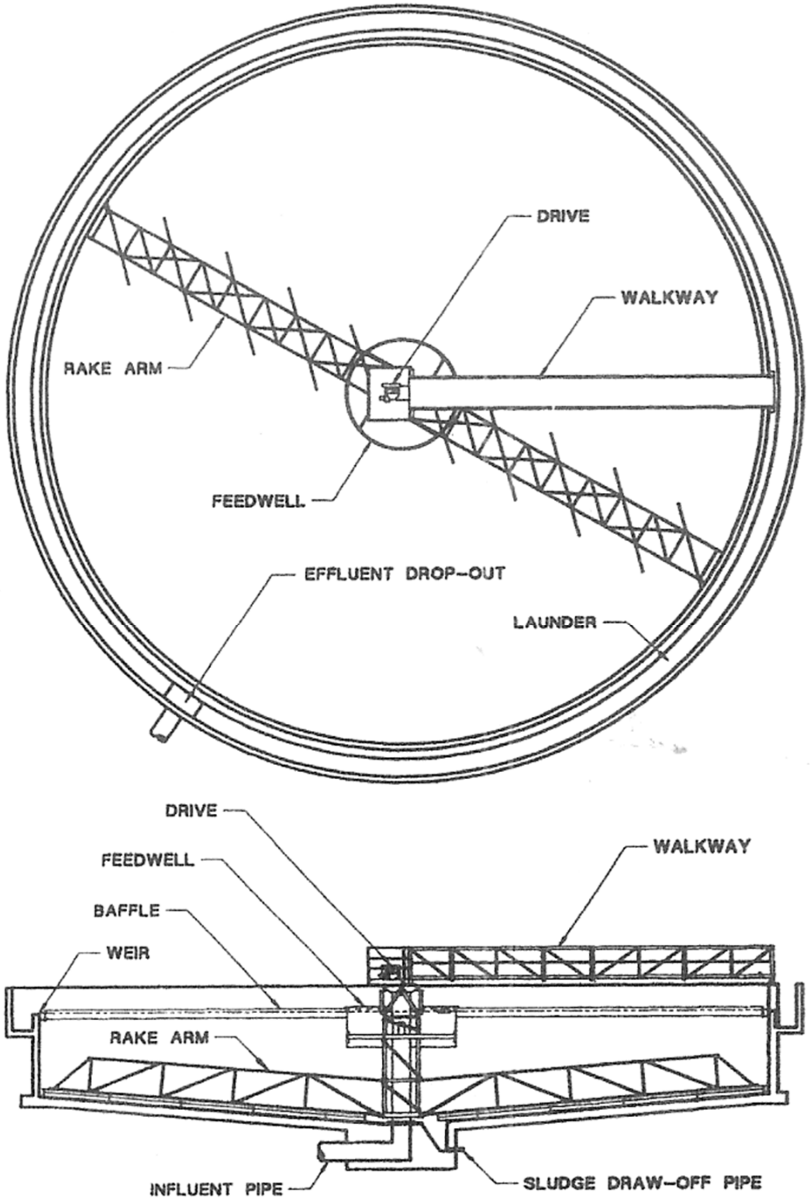


FIGURE 7.19 Circular radial-flow clarifier. (*Source:* Courtesy of Baker Process Equipment Co., Salt Lake City, Utah.)

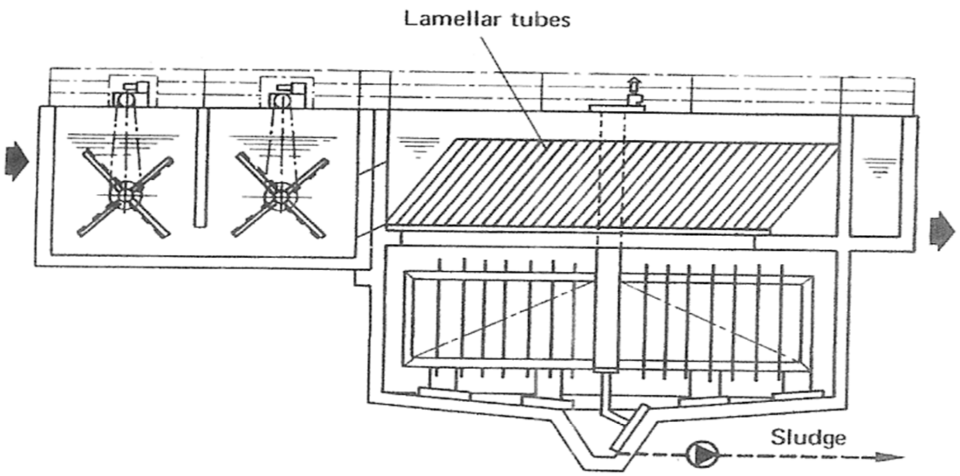
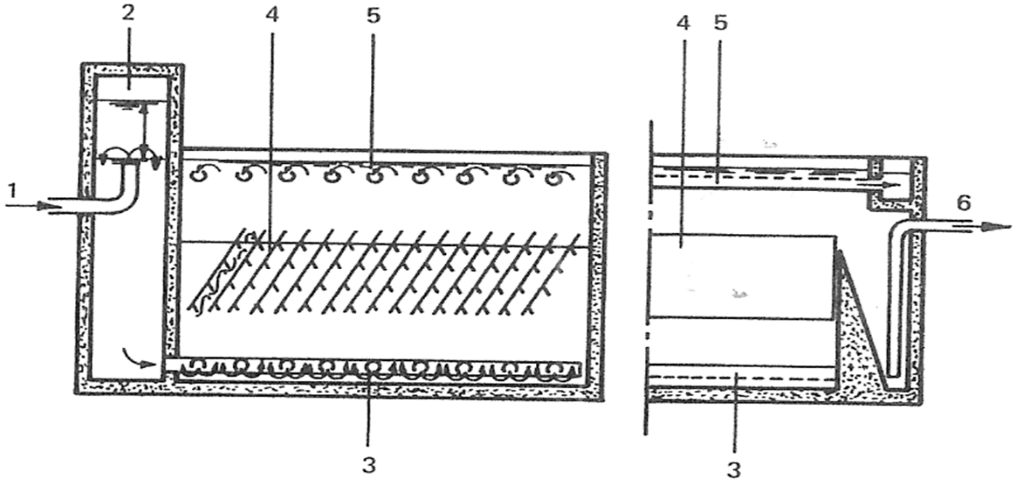


Fig. 7.6 Lamella separator and thickener. (Passavant Ltd.)



1 Raw water inlet
2 Vacuum chamber
3 Perforated pipes for water distribution
4 Plate system
5 Perforated pipes for clarified water collection
6 Sludge discharge

Fig. 7.7 The 'Super Pulsator' clarifier. (Degremont Laing Ltd.)

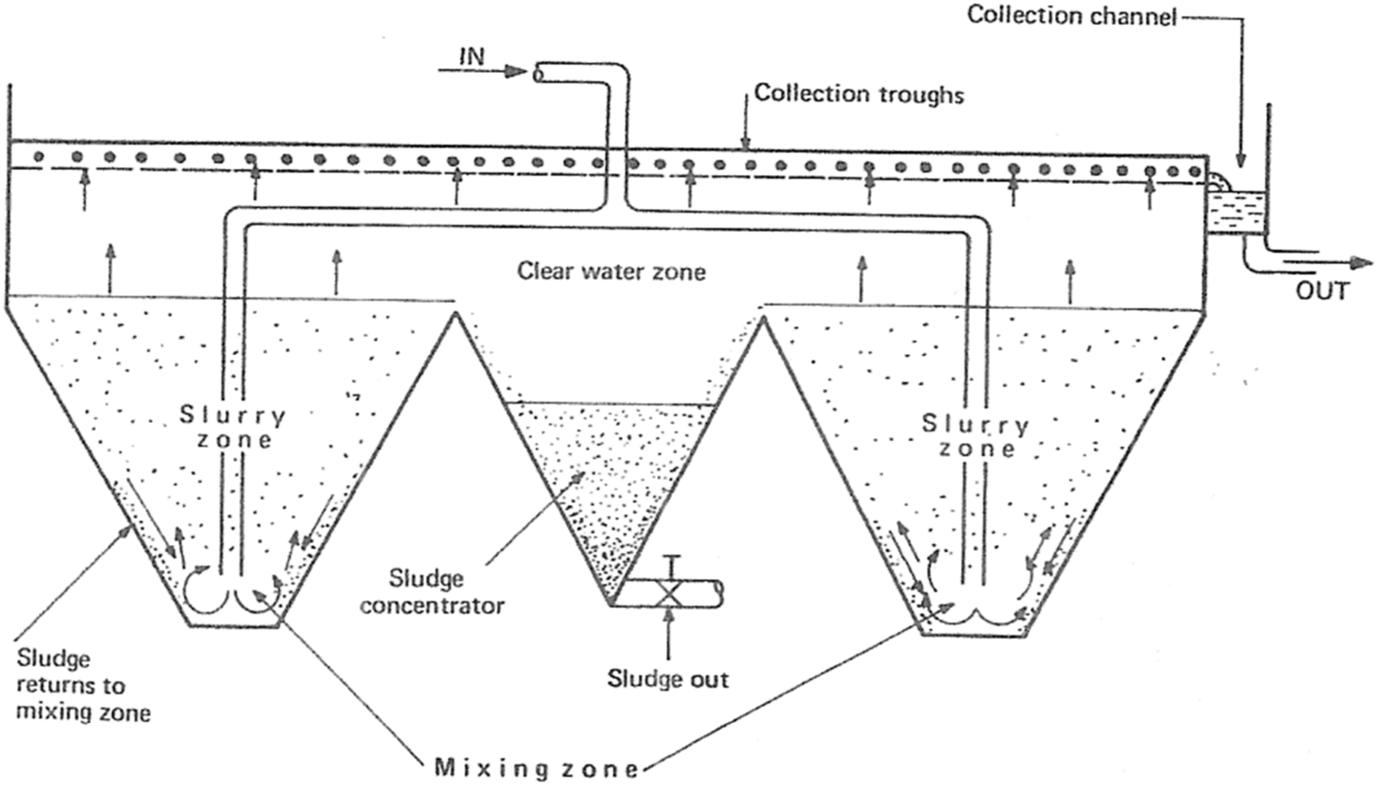


Fig 13.5 Arrangement of hopper-bottomed 'sludge blanket' clarifier with separate sludge concentrator

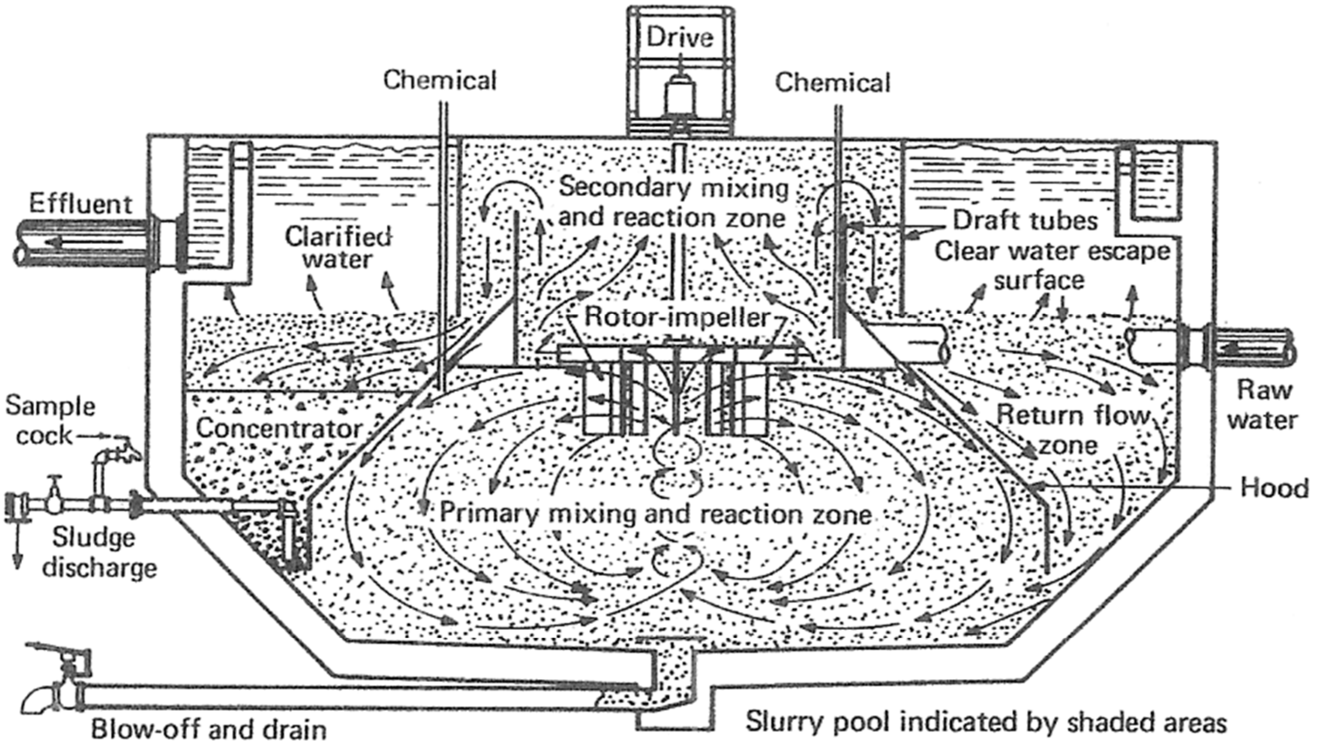


Fig 13.9 Solids contact clarifier with mechanical circulation, gravity sludge return and peripheral sludge concentrator *(Courtesy: Degremont)*

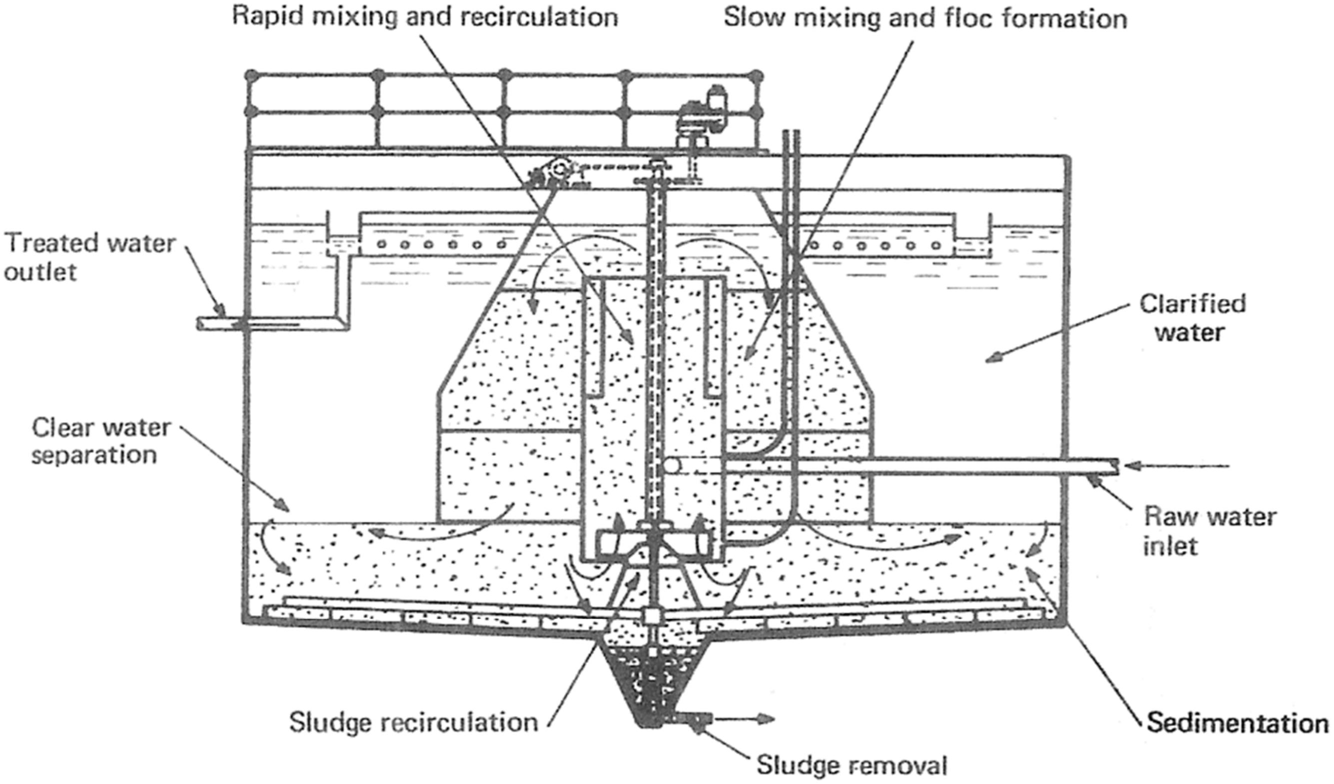


Fig 13.8 Solids contact clarifier with mechanical circulation and sludge scraper, with central sludge withdrawal *(Courtesy: William Boby — Reactivator)*

Pulsator

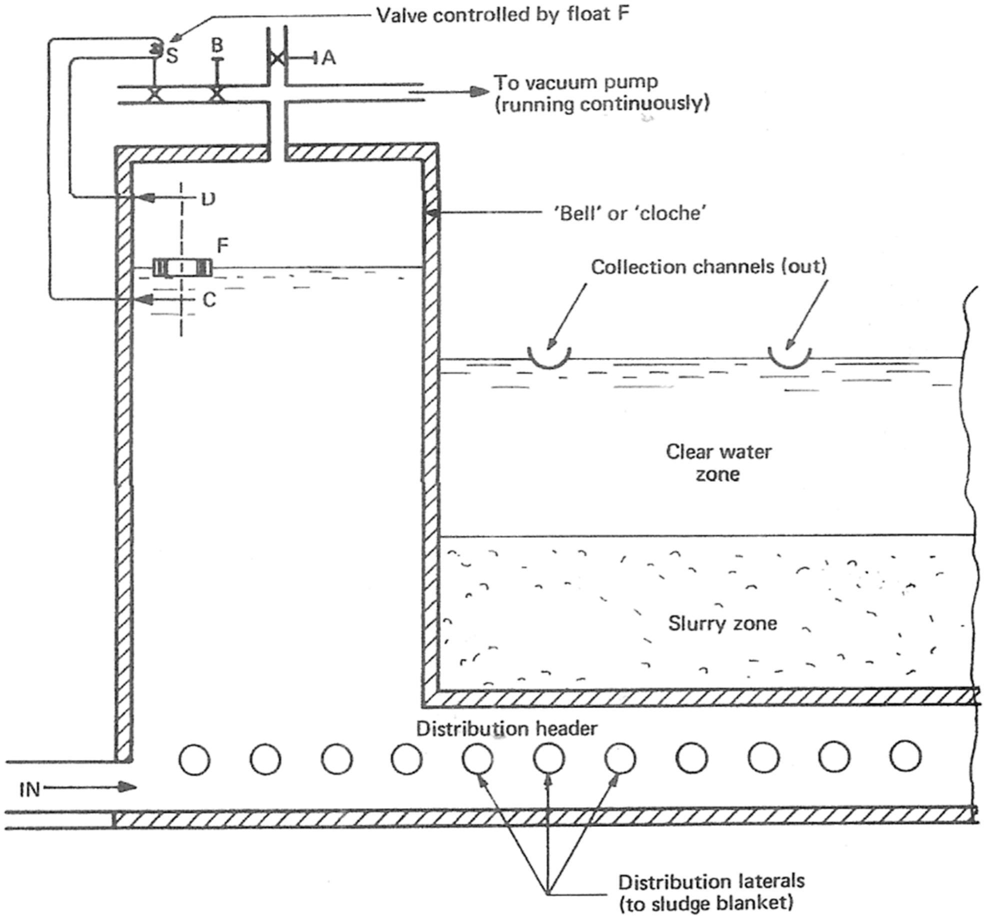


Fig 13.7 Pulse control in a pulsator

DISSOLVED AIR FLOTATION

- Flotation processes have been used in the mining and chemical processing industries for over 100 years
- The ancient Greeks used this process to separate minerals from the gangue over 2000 years ago
- Dissolved-air flotation was patented in 1924 to Niels Peterson and Carl Sveen in Scandinavia.

DISSOLVED AIR FLOTATION

- The use of DAF in the treatment of waste water and potable water began in the late 1960's
- dissolved air flotation has been used for water clarification in Europe especially in the Scandinavian countries for more than 20 years.

DISSOLVED AIR FLOTATION

- In the United Kingdom, the first full-scale water treatment plant using this process was commissioned in 1976 at the Glendye Treatment Works of the Grampian Regional Council, Scotland
- Flotation may be defined as the transfer of a solid from the body of a liquid to the surface by means of bubble attachment
- Different methods of bubble generation give rise to different types of flotation processes.

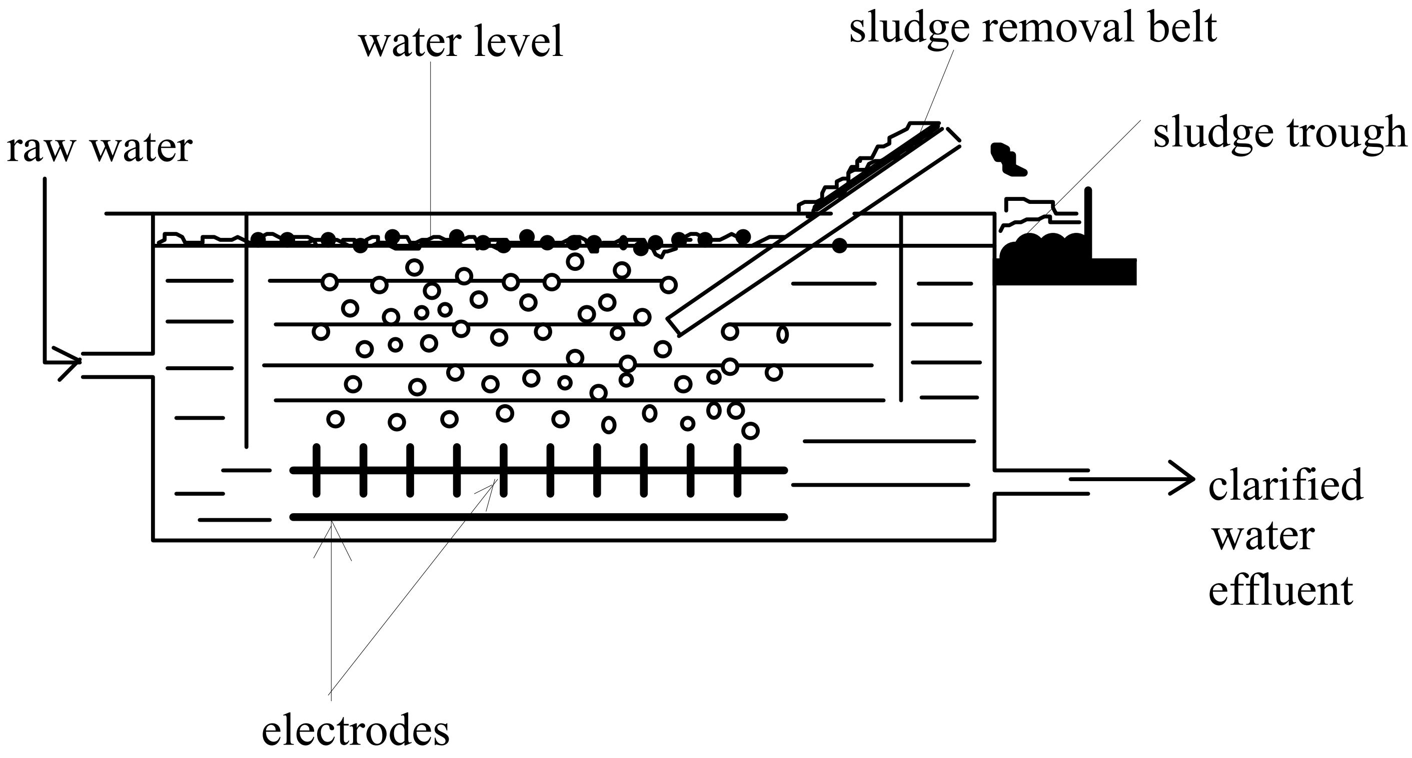
There are three types of flotation process:

- 1. Electro- or electrolytic flotation.
- 2. Dispersed air flotation.
- 3. Dissolved air flotation.

Electro-flotation

- bubbles (oxygen and hydrogen) are generated by passing an electric current between two electrodes in a dilute aqueous solution
- The anodes are prone to corrosion while the cathodes are subject to scaling by carbonate deposition
- The bubbles produced by the electro-flotation process are normally small
- This process is suitable for effluent treatment (Ho and Chan, 1986), sludge thickening and water treatment installations of 10 to 20 m3/hour

Electro-flotation



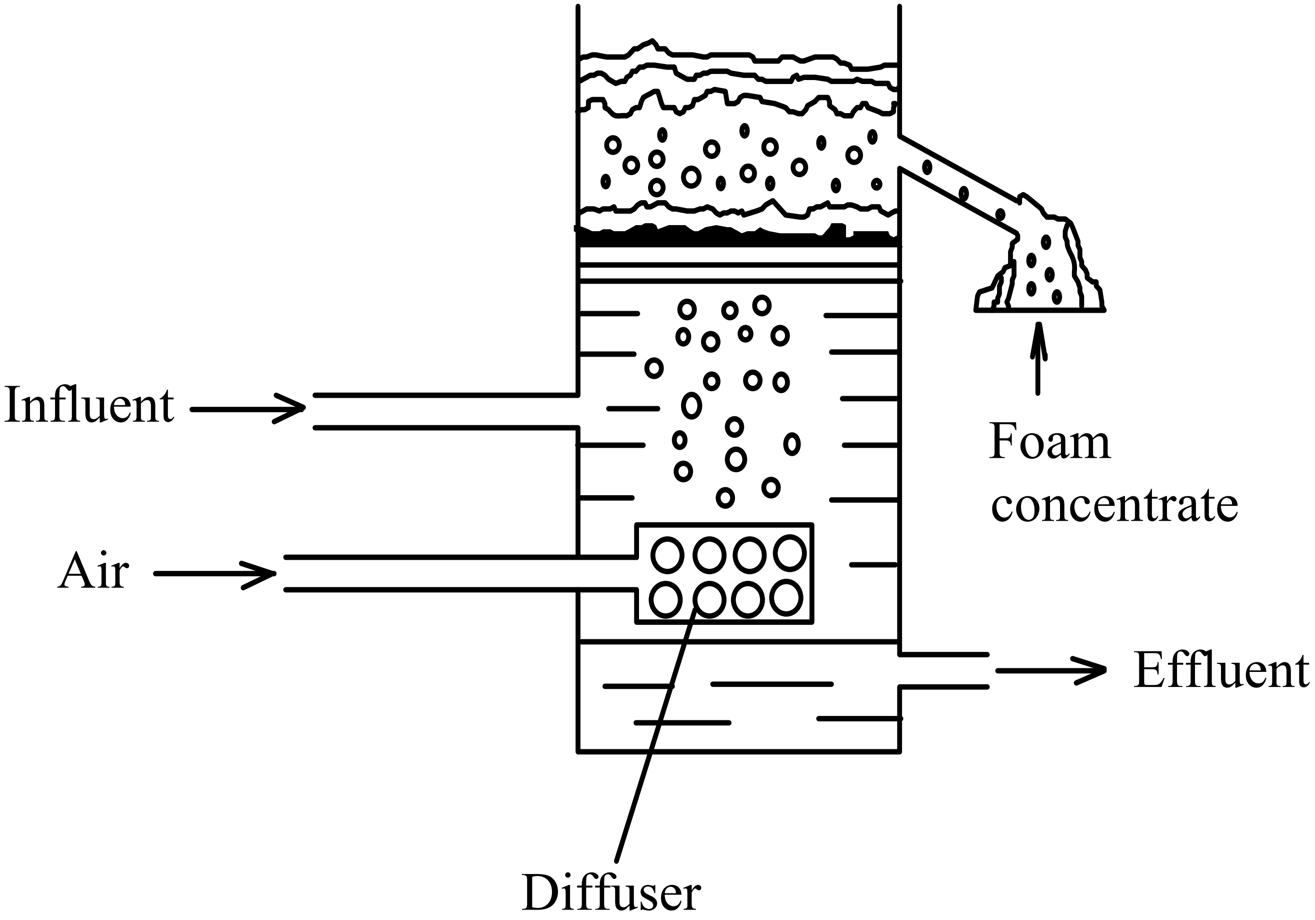
Dispersed Air Flotation

- has two different systems to generate bubbles namely, foam flotation and froth flotation.
- In the foam flotation system, bubbles are generated by forcing the air through a porous media made out of ceramic, plastic or sintered metal
- In the froth flotation system (as shown in Figure 2.3) a high speed impeller or turbine blade rotating in the solution is used to produce air bubbles

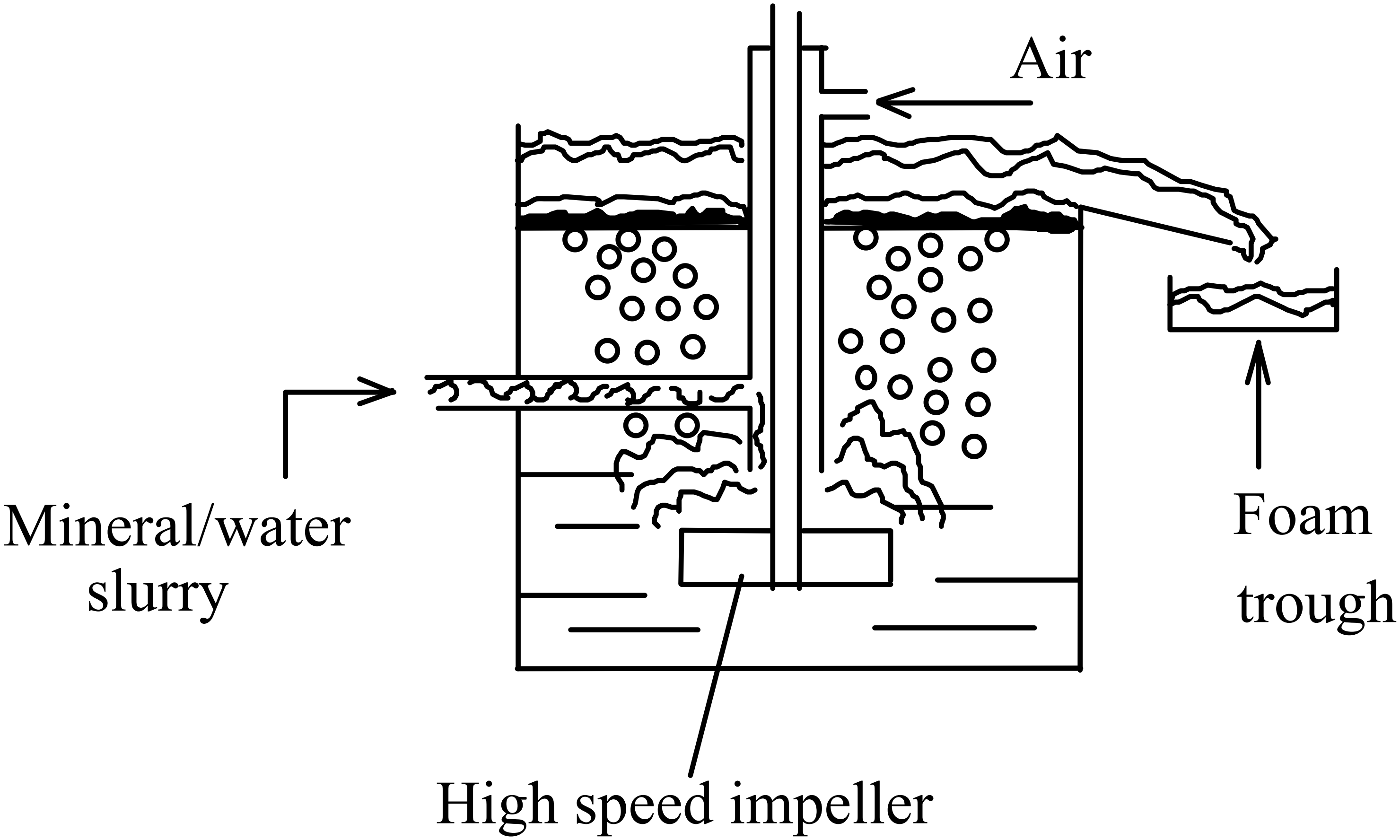
Dispersed Air Flotation

- This process produces large air bubbles of more than 1mm in diameter
- This process has been assessed for potable water treatment but was not suitable, mainly for the separation of minerals and removal of hydrophobic materials such as fat emulsions in selected waste water treatment

Foam flotation



Froth flotation



Dissolved Air Flotation (DAF)

- Three main types of dissolved air flotation
- 1. Vacuum flotation
- 2. Micro-flotation
- 3. Pressure flotation

Vacuum Flotation

- It is used for the recovery of fibres in the pulp and paper industry
- In this process, water is saturated with air under atmospheric pressure and then a vacuum is applied to the flotation tank.

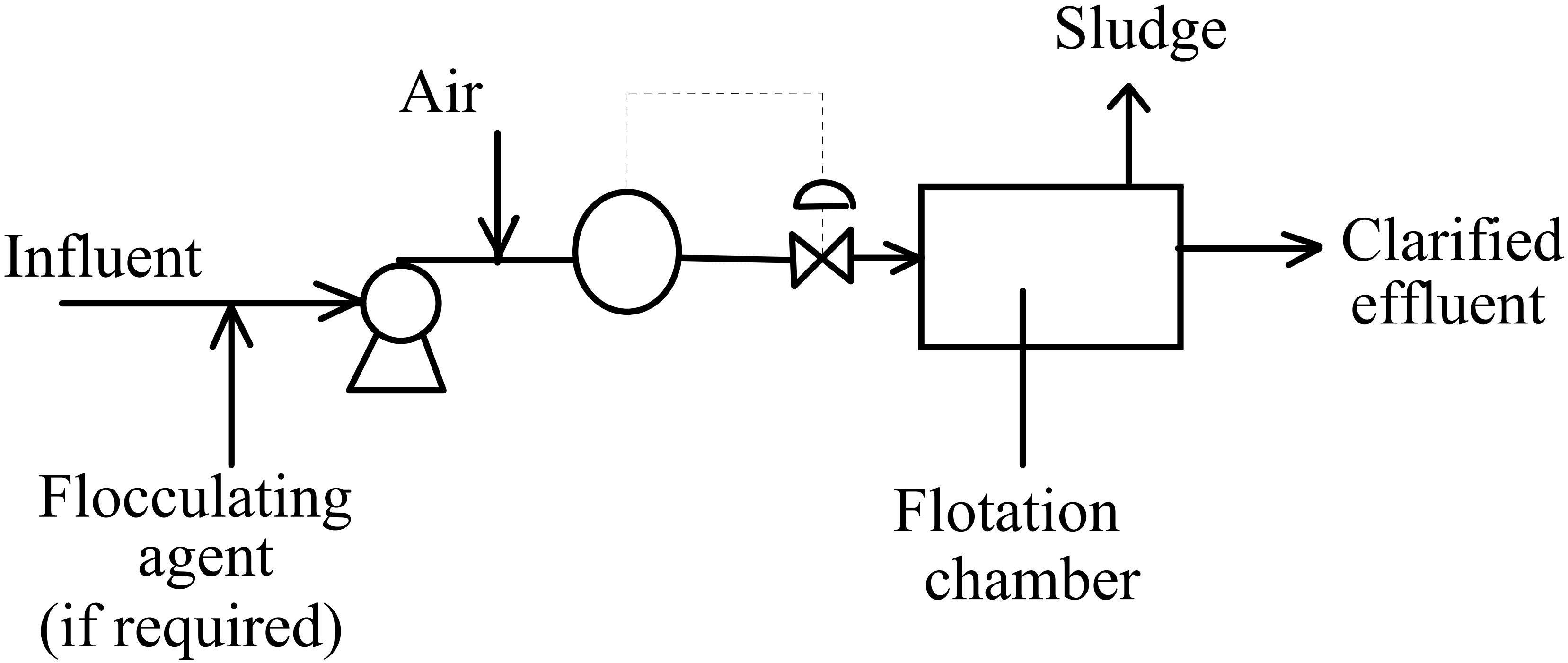
Micro-flotation

- for the treatment of domestic sewage and industrial effluents
- In the micro-flotation process, water is passed down and up a shaft of approximately 10 metres deep. The whole water column will be subjected to hydrostatic pressure. Water will be aerated as it passes the down-flow section and air dissolves in the water due to an increase in hydrostatic pressure

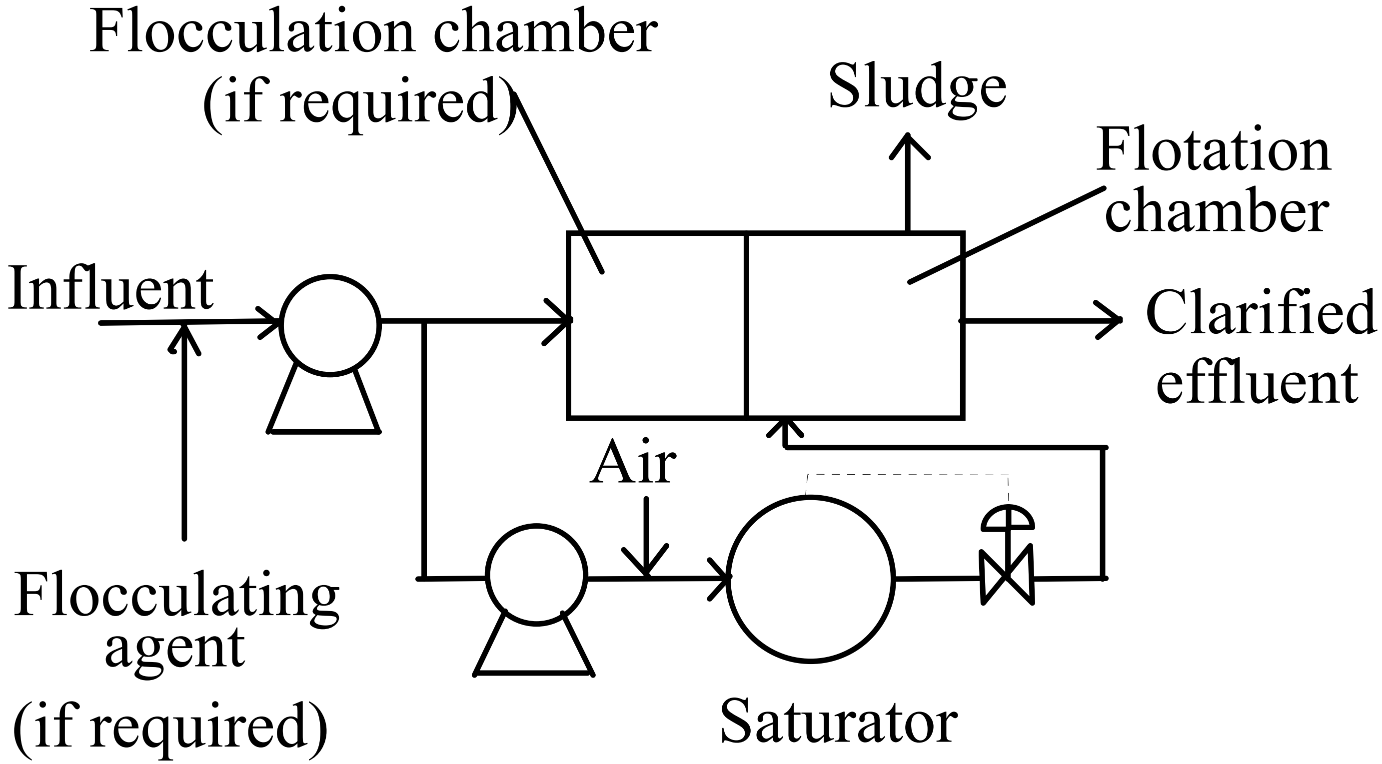
Pressure Flotation

- Pressure flotation is the most common process used in dissolved air flotation. There are three basic types of pressure dissolved air flotation processes:
- Full-flow pressure flotation
- Split-flow pressure flotation
- Recycle-flow pressure flotation

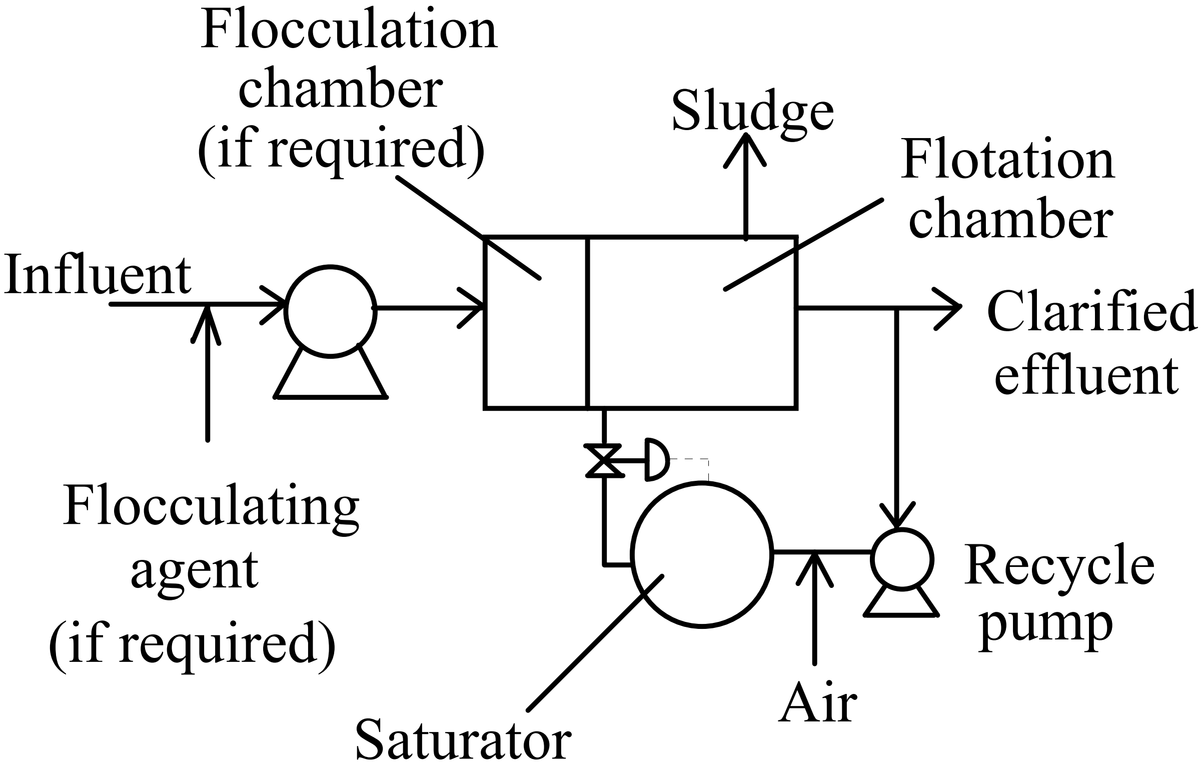
Full-flow pressure flotation (Source: Zabel, 1980)



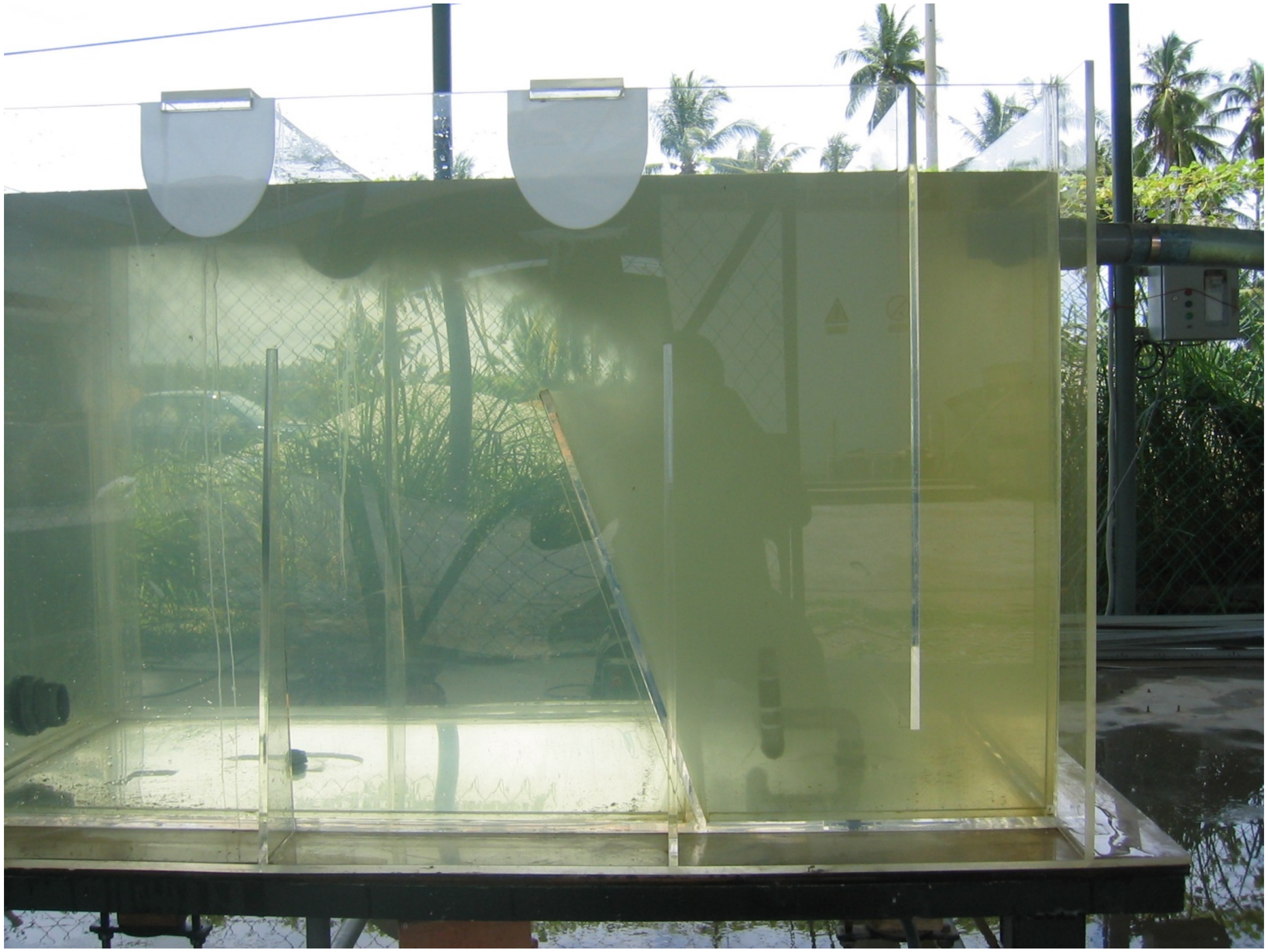
Split-flow pressure flotation (Source: Zabel, 1980)



Recycle-flow pressure flotation (Source: Zabel, 1980)



Dissolved Air Flotation



Dissolved Air Flotation

Saturator

Typical design and operation parameters for DAF

PARAMETER	DESIGN VALUES RANGE	DESIGN VALUES TYPICAL
CHEMICAL PRETREATMENT		
Coagulation dose	Determine from jar test	
Flocculation time (minutes)	5 - 30	20
G value (per second)	10 - 150	70

Typical design and operation parameters for DAF -

FLOTATION TANK DESIGN:

PARAMETER	DESIGN VALUES RANGE	DESIGN VALUES TYPICAL
Detention time (minutes)	5 - 15	10
Depth (m)	1.0 - 3.2	2.4
Overflow rate (m/hr.)	5 - 15	8
Freeboard (m)	0.1 - 0.4	0.3

Typical design and operation parameters for DAF - AIR

SATURATION SYSTEM AND SLUDGE:

PARAMETER	**DESIGN VALUES RANGE**	**DESIGN VALUES TYPICAL**
Operating pressure (KPa)	350 – 620 (50 - 90psi)	485 (70psi)
Recycle ratio (%)	6 - 30	6 - 12
Bubble size (μm)	10 - 120	40 - 50
Saturator efficiency, packed (%)		90
Saturator efficiency, unpacked (%)		70
SLUDGE:		
Percent solid (%)	0.2 - 6	3

DAF performance related to water quality characteristics

PARAMETERS	FINDINGS
1.Algae Removal	(a) Better than sedimentation
	(b) Alum performed better than ferric sulphate
	(c) 95% removal compared with 65% from sedimentation
2. Colour and turbidity removal	(a) DAF performed same as sedimentation
	(b) Colour of 45° Hazen and turbidity less than 100 FTU is limiting point for DAF
	(c) DAF removed 70% of turbidity and 79% of suspended solids
	(d) Removal of true colour at the same pH and coagulant dose, DAF performed same as sedimentation
	(e) Not much different in result using ferric sulphate or alum
	(f) Turbidity removal not effective in extreme winter conditions.
	(g) DAF removed 30 to 45.7% of turbidity and 40.8 to 50.5% of colour
3. Residual coagulant concentration	(a) DAF performed the same as sedimentation
4. Bacteria	(a) 99% could be removed
5. Protozoa	(a) *Cryptosporidium* removal more effective using DAF compared with sedimentation

DAF performance related to process parameters

PARAMETERS	FINDINGS
1. Performance at flotation stage	(a) Dependent on the efficiency of flocculation
2. Velocity gradient in flocculation	(a) Non-tapering: (i) 70 per sec. (ii) 60 to 80 per sec.
	(b) Tapered (25 to 80 per sec.)
3. Retention times	(a) In flash mixer: 1 1/2 minutes
	(b) In flocculation tank: 7 min.;9 min.;12 min.;8 min.;20 to 127 min.;5 to 120 min.
	(c) In flotation tank 20 min.,5 1/2 min.
4. Overflow rate	(a) 2 to 4 mm/sec by flotation and 0.3 to 1.3 mm/sec by sedimentation
	(b) DAF:Sedimentation by the ratio 6:1 to 12:1

Theory of Flotation

- The principles of flotation based on bubble generation, bubble attachment and solid separation.

For bubble-particle attachment several theories were forwarded by various researchers:

- Bubbles grow by precipitation from a supersaturated solution on the surface of the particles (Taggart, 1945)
- Bubble-particle attachment involves chemical and physical aspects such as surface energy, surface tension, adsorption, contact angle, polarity, surface reactivity, surface condition and adding air-adhering agents to some minerals (Gaudin, 1939)

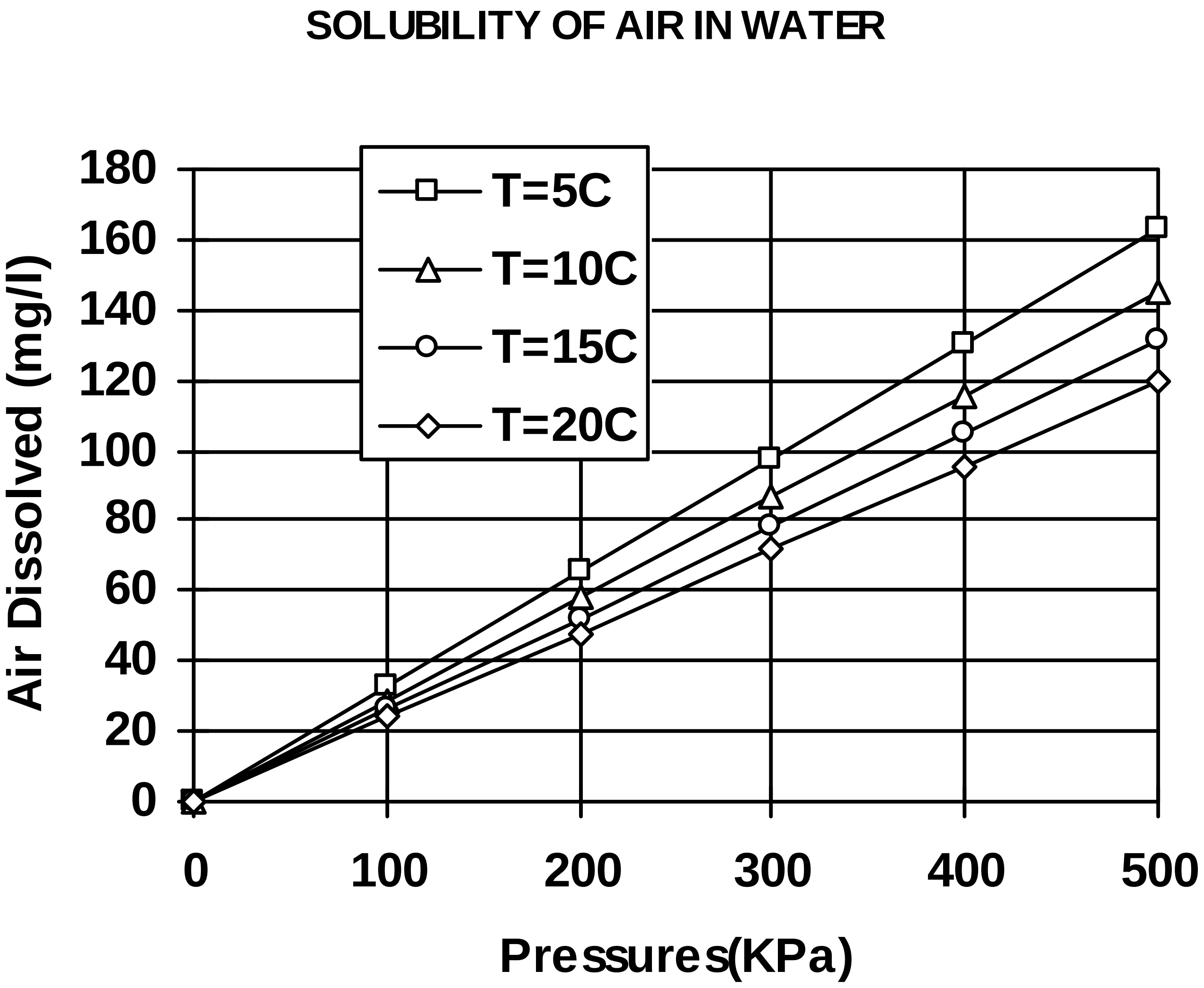
-----for bubble-particle attachment several theories were forwarded by various researchers:

- An 'induction time' is required to allow the thin liquid layer between bubble and particles to drain away so that coalescence can occur (Sutherland, 1948)
- If the surface conditions of the particles are appropriate, the bubbles will collide and coalesce with the particles (Klassen and Mokrousov, 1963)
- The particle follows its trajectory as it approaches a bubble and this trajectory will be dependent on viscous effects and Reynolds number (Flint and Howarth, 1971)

The following mechanisms are important for the bubble attachment process to take place:

- 1. Adhesion of gas bubbles with the suspended phase as a result of collisions or by nucleation.
- 2. The trapping of gas bubbles in a floc structure
- 3. The absorption of gas bubbles into a floc structure as it is formed

Solubility of air in water (Henry’s Law)



Filtration

- To remove fine inorganic & organic particles from the water.
- Sand filter for water supply.
- Vacuum filters & filter press are used for removing water from sludge.
- Diatomaceous earth filters for municipal water supplies.

Mechanical Straining

- Granular filter remove particles much smaller than the dimensions of the interstices between their grains.
- When larger particles of impurities lodged in a space between two grains, the portion of opening not occupied by the particles will provide smaller opening to trap smaller particles. If this is the case, the surface layers would rapidly become clogged and fine particles would be likely to pass through the remaining depth without being caught or detained.
- However granular filter capable of capturing very fine particles.
- Mechanical straining account for only a minor part.

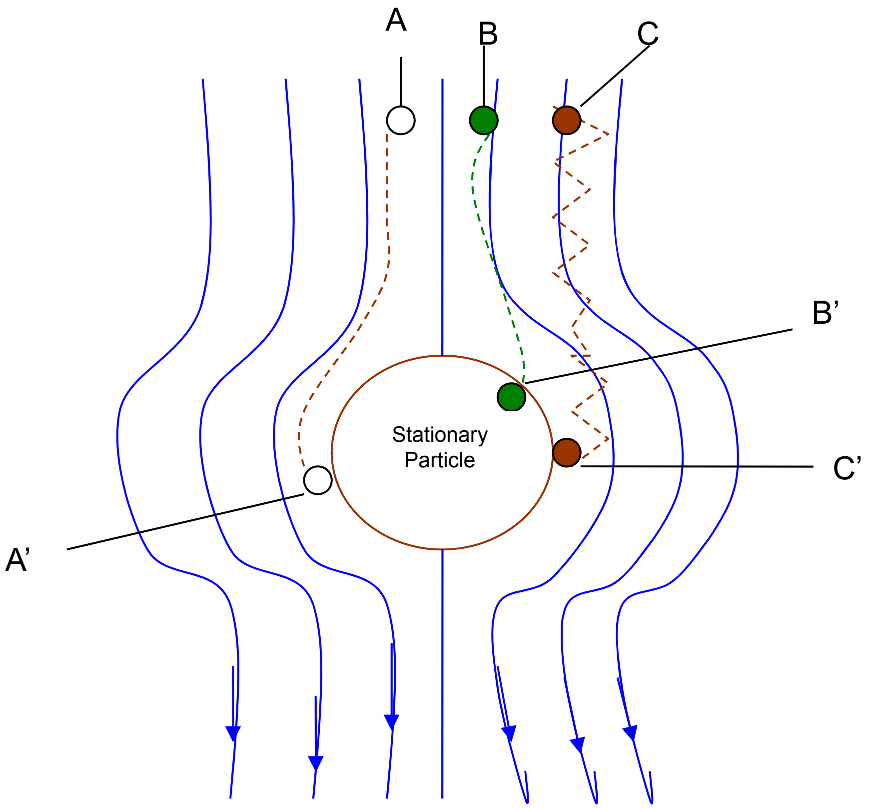
Adsorption

- Three essential parts in filtration:
- the bed fixed solid.
- the water passing through the interstices between the fixed solid.
- the solid impurities suspended in the water.

- -Adsorption of particles of impurities onto the fixed bed is a major factor in a successful filtration through porous media.
- -Efficiency depends on surface properties of both adsorbing matrix & small particles.
- -Small particle in close proximity to a solid surface is subject to electrical attraction or repulsion & to the attraction caused by Van der Waals forces.
- -it is also subject to hydraulic forces resulting from the movement of water.

Transport

- Flow is laminar
- Three mechanism by which particles are transported into contact with the filter matrix:
- 1. Interception
- 2. Sedimentation
- 3. Diffusion



Interception – particle A streamline for A to A'.
Sedimentation – particle B is deflected from streamline by gravity.
Diffusion – particle C is buffeted by Brownian motion.

Interception & sedimentation is effective as the particle size increases.
Effectiveness of diffusion increases with a decrease in size.

Types of filters

- Slow sand filter
- Rapid sand filter
- Pressure filter
- Roughing filter – used at preliminary stage

Slow sand filter

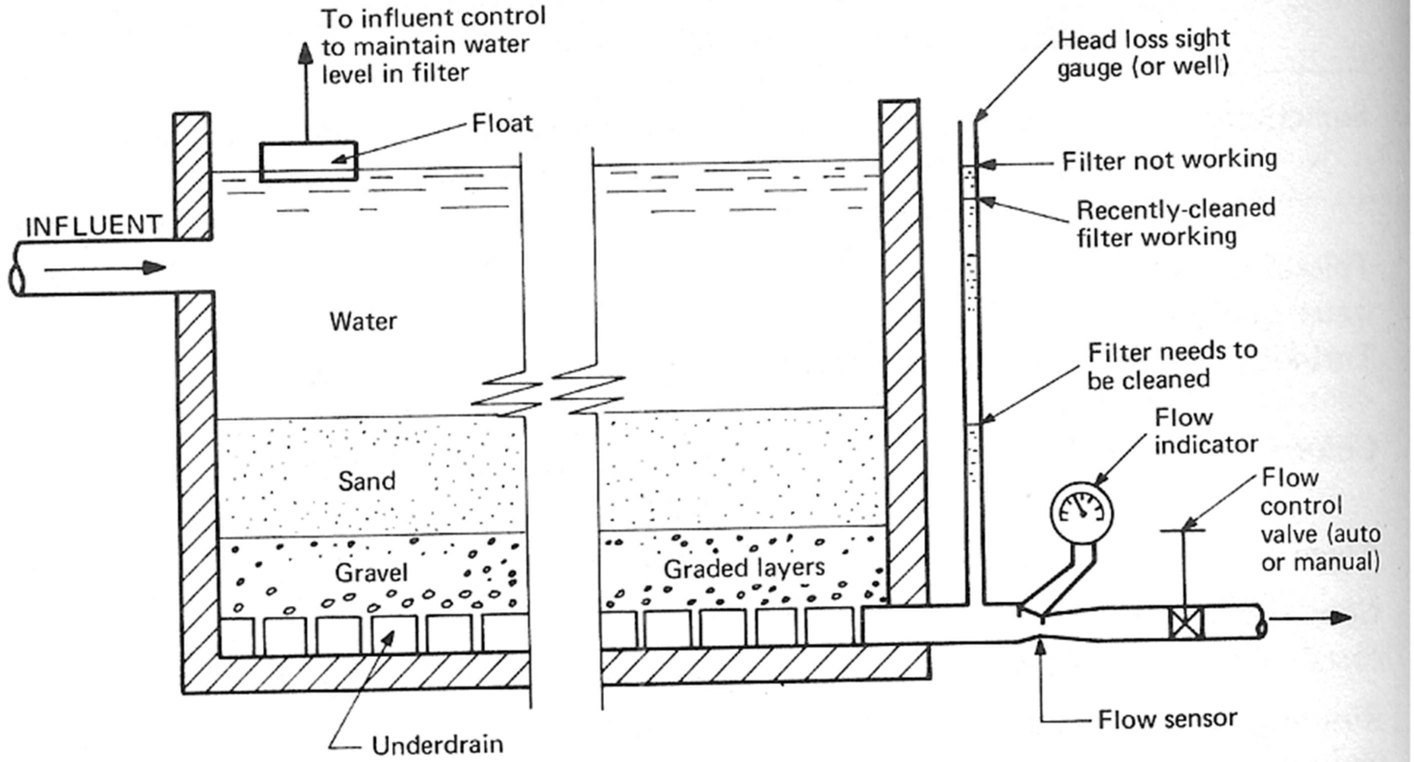


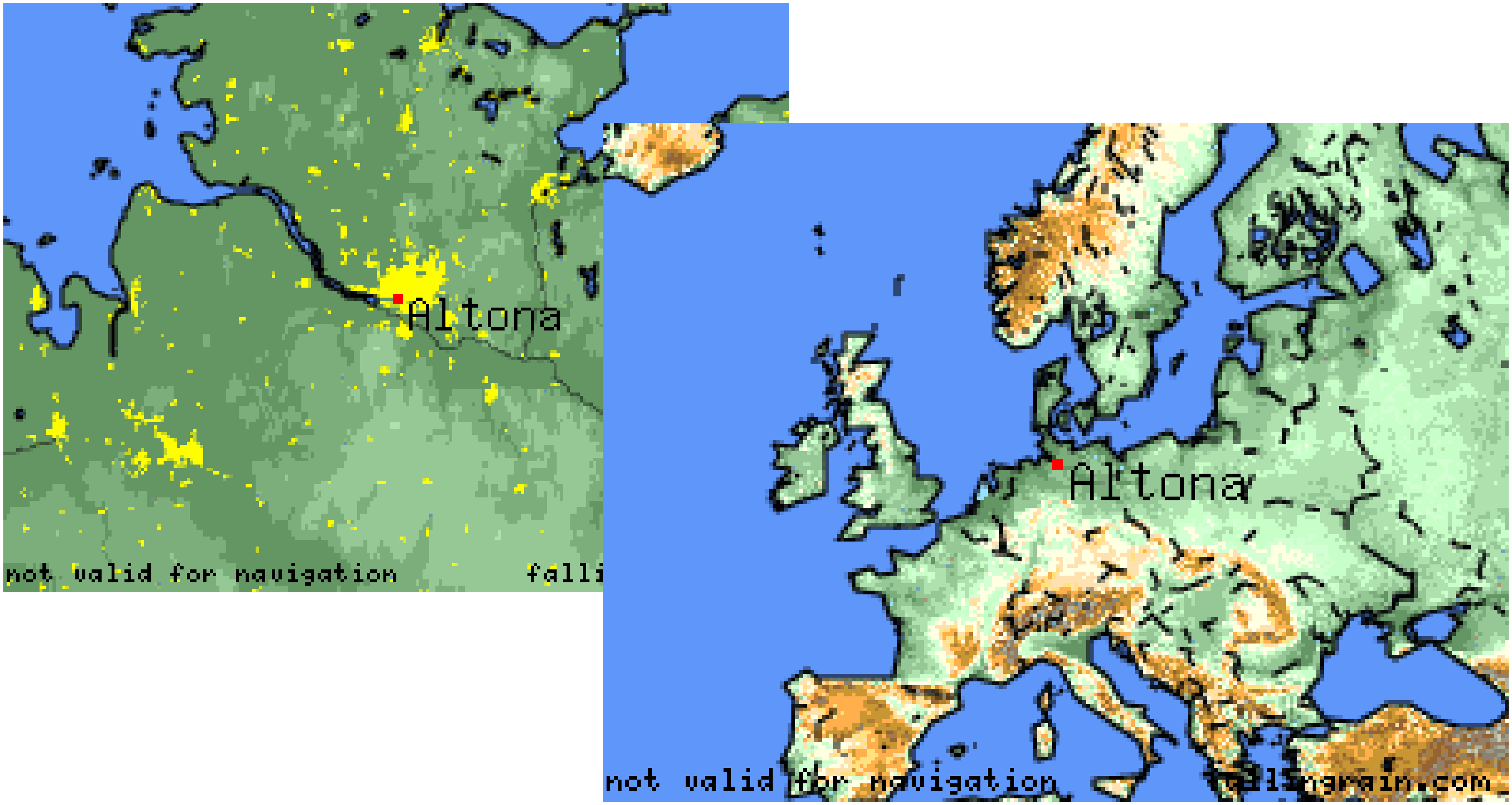
Fig 13.14 Diagrammatic section of slow sand filter

History for slow sand filter

- 1804 – filter was tested for industrial used in Scotland
- 1829 – first filtration for public water supply in London
- 1852 – filtration was required in accordance to water act in London for surface water supplies.
- 1892 – cholera epidemic in Hamburg, 7582 of the 580,000 population died. Water supply for Hamburg was abstracted from River Elbe, but treatment was only by sedimentation. Nearest town called Altona using the same source of water but was filtered before supplied to the consumers and not record of death.

River Elbe, Dresden

- Altona is part of Hamburg, N Germany, a port on the Elbe River. Its manufactures include chemicals, textiles, and tobacco products. There are fisheries, and the district is a rail center. Founded as a fishing village in the 16th cent. and later one of the first free ports in N Europe, Altona was incorporated into Hamburg in 1937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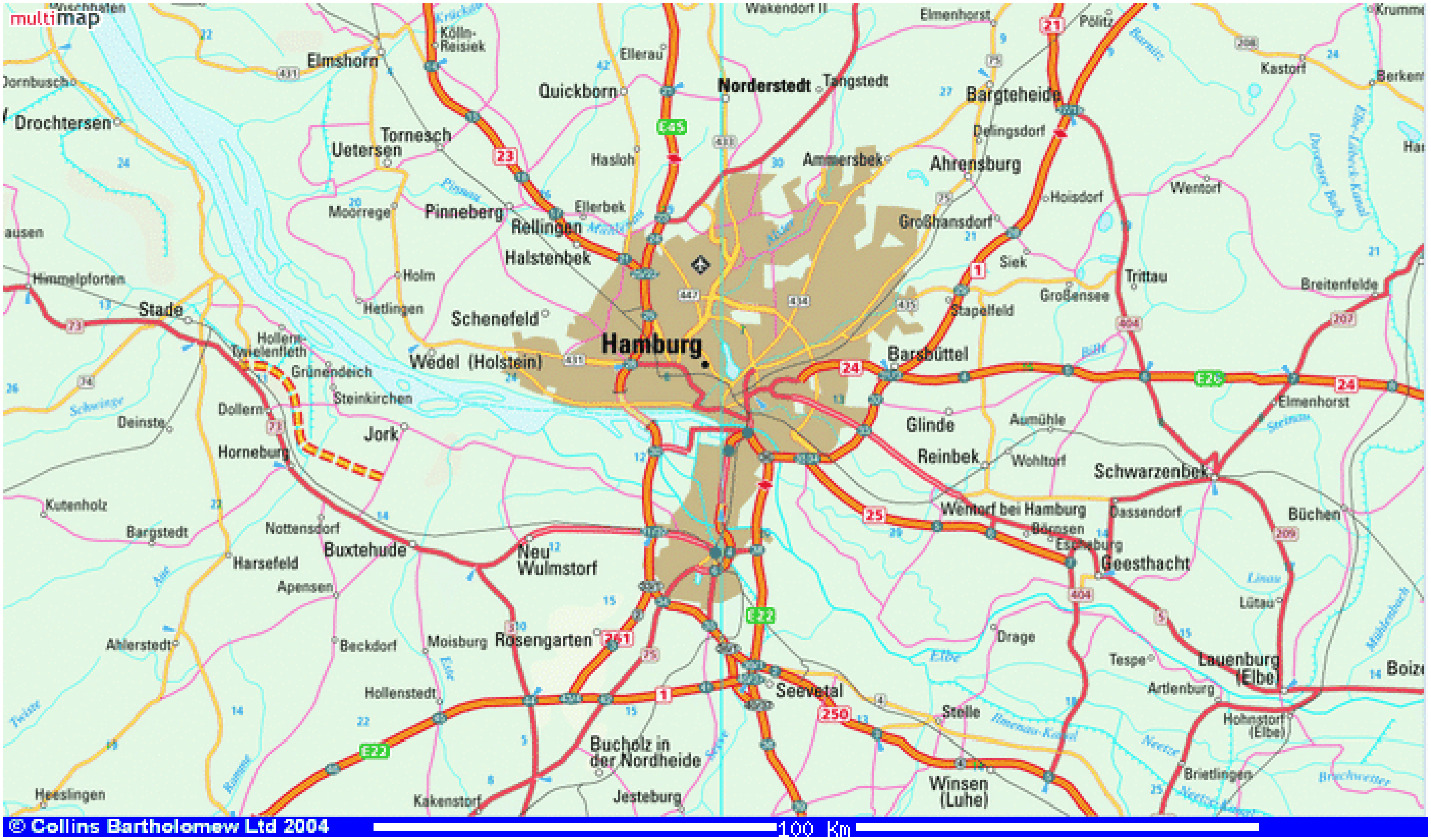
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Quickborn
Ellerau
Norderstedt
Tangstedt
Wakendorf II
Elmenhorst
Pölitz
Krummesse
Kastorf
Berkenthin
Bargteheide
Delingsdorf
Ammersbek
Ahrensburg
Hoisdorf
Wentorf
Großhansdorf
Siek
Trittau
Breitenfelde
Großensee
Stapelfeld
Barsbüttel
Glinde
Aumühle
Reinbek
Wohltorf
Schwarzenbek
Elmenhorst
Wentorf bei Hamburg
Börnsen
Escheburg
Dassendorf
Büchen
Geesthacht
Lütau
Tespe
Lauenburg (Elbe)
Artlenburg
Boizenburg
Hohnstorf (Elbe)
Brietlingen
Drage
Stelle
Winsen (Luhe)
Seevetal
Buchholz in der Nordheide
Jesteburg
Kakenstorf
Rosengarten
Moisburg
Hollenstedt
Beckdorf
Ahlerstedt
Heeslingen
Apensen
Harsefeld
Bargstedt
Kutenholz
Buxtehude
Neu Wulmstorf
Nottensdorf
Horneburg
Jork
Dollern
Deinste
Stade
Himmelpforten
Drochtersen
Dornbusch
Wischhafen
Hollern-Twielenfleth
Grünendeich
Steinkirchen
Hamburg
Wedel (Holstein)
Schenefeld
Hetlingen
Holm
Moorrege
Uetersen
Tornesch
Pinneberg
Rellingen
Halstenbek
Ellerbek
Hasloh
Elbe
Alster
Bille
Pinnau
Krückau
Schwinge
Este
Seeve
Ilmenau-Kanal
Neetze
Elbe-Lübeck-Kanal
Steinau
Linau
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100 Km

Mechanisms of slow sand filtration

- Mechanical straining
- Biological activity
- Although gravitational settling and adsorption are of importance. Other mechanisms such as inertial and centrifugal forces, mass attraction, electrostatic are of lesser importance.

- As a clean filter is returned to operation following cleaning the alluvial mud, algal, planktonic and protozoan matters are strained out to form a layer on top of the sand and also intimately mixed with the topmost grains. This is the filter skin or ‘schmutzdecke’ which acts both as a very fine filter coat and as an active biological zone. In this schmutzdecke, and at the top of the sand layer, most of the suspended solids in the water are filtered out.

- Pathogenic bacteria adsorbed on to the sand or trapped in the schmutzdecke are a prey adverse conditions and to predators ranging from bacteriophages to protozoa. Very few pathogenic bacteria escape through a well designed and operated slow sand filter and removal can be expected to be to greater than 99.9%. Below the ‘schmutzdecke’ bacterial activity continues for about 400mm

Comparison of slow sand filter with rapid sand filter

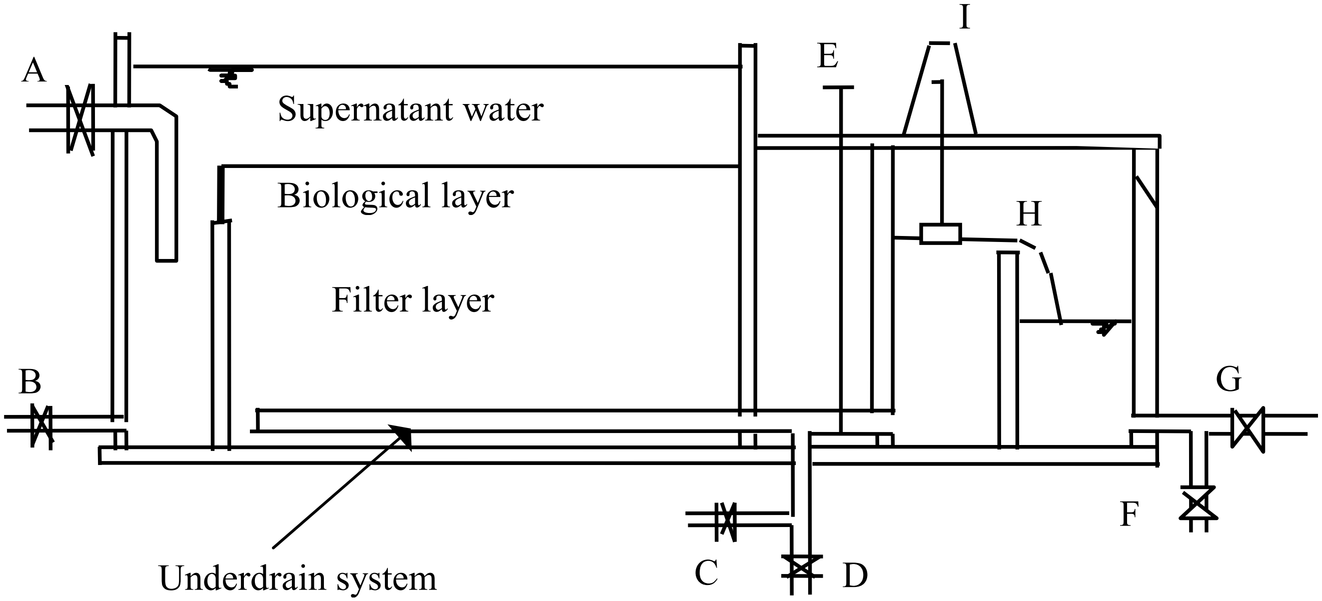
Parameter	Slow sand filter	Rapid sand filter
Filtration rate (m/hr)	0.1 - 0.4	5 - 20
Effective size of sand (mm)	0.15 - 0.4	0.6 - 1.0
Non-uniformity coefficient	1.7 - 3.0	1.3 - 1.5
Penetration of suspended solids	Superficial	Deep
Method of cleaning	Scraping off surface layer	Upward flow or backwashing fluidised the bed
Time between cleaning (day)	30 - 150	1 - 3
Inlet water requirement	Low turbidity < 50NTU	Coagulation, flocculation & sedimentation
Basic process	biologi	fizikal
Economical aspect	Unskilled labours	Complicated design with complex equipment
Water loss	Water wastage during maturation	1 to 4 to 6% of filtered water

Design criteria for rectangular slow sand filter unit

- Total depth 2.5 to 3.0 m.
- constructed from reinforced concrete, ‘ferrocement’, stones or bricks and must not be cracked or leaked
- Plan area up to 5000 m^2.
- At least 2 filters in parallel so that filter can be operated if the other needs to be cleaned.
- Depth of chamber will be as follows ukur (Schulz and Okun, 1984):

Free board	0.20 m
supernatant water	1.00 m
Initial filter media	1.00 m
Supporting gravel	0.30 m
Underdrained brickworks	0.20 m
Total	2.70 m

Slow sand filter



A= inlet valve, B= supernatant drain valve, C= backfilling valve, D= drained off valve, E=regulating valve, F=drain valve, G= treated water control valve, H= Outlet weir and I= flow calibration system.

Rapid sand filter

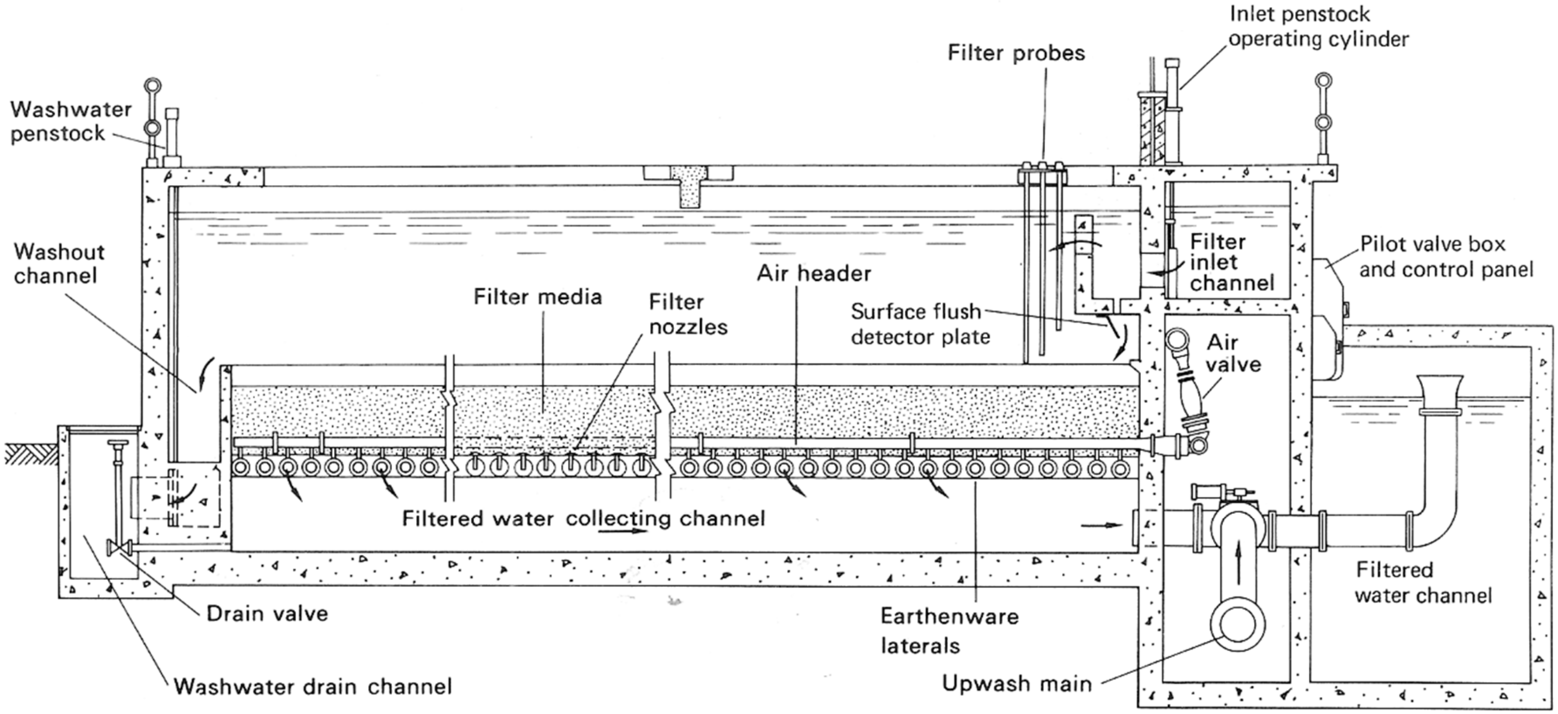


Fig. 7.8 Rapid gravity filter. (Paterson Candy International Ltd.)

Rapid sand filter

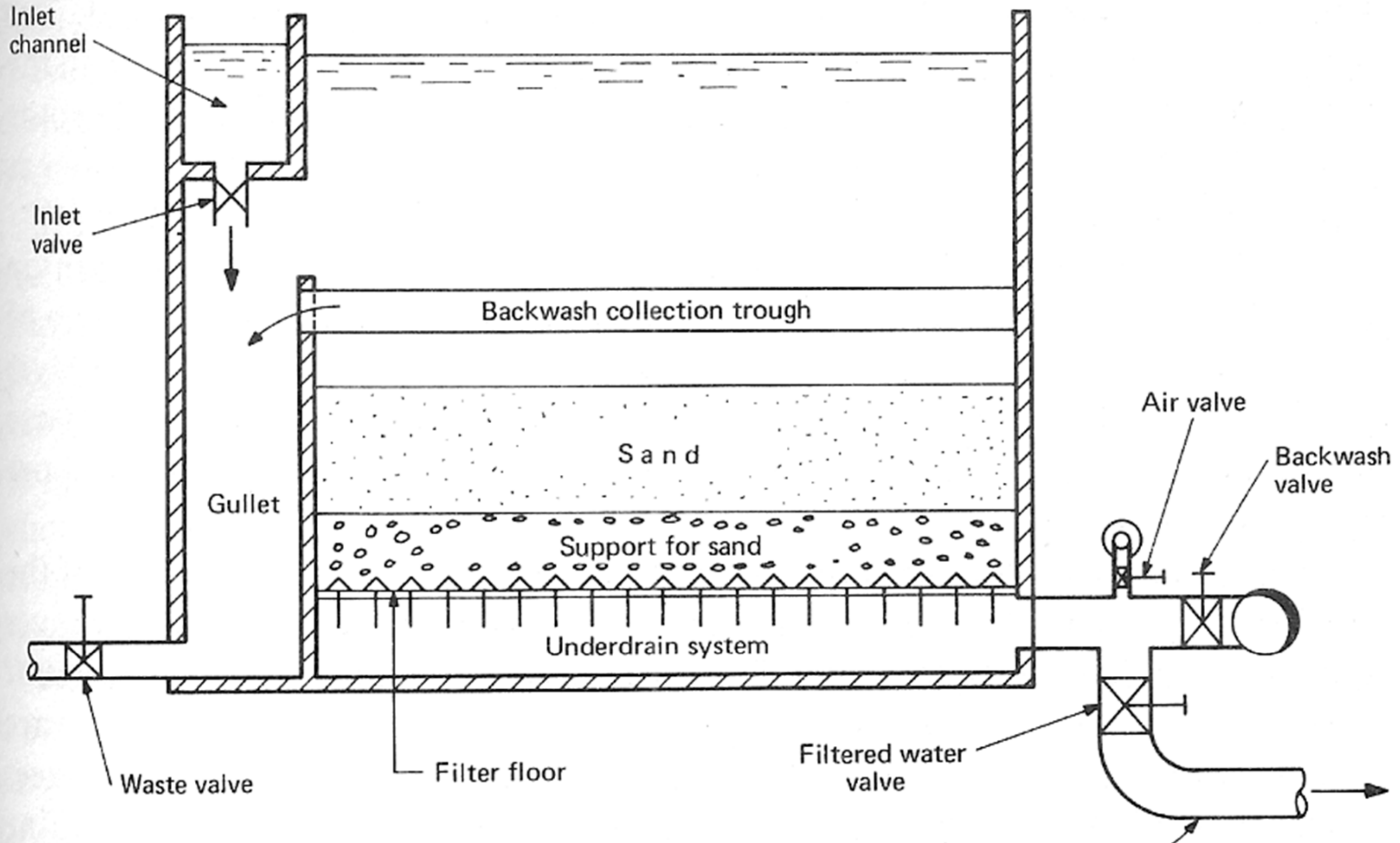


Fig 13.15 General arrangement of a typical rapid sand filter

Rapid sand filter

- Higher filtration rate of 3 to 6 m/hour compared to slow sand filter
- Filter media consist of:
- Upper sand layer from 0.45 – 0.95 mm in size, with depth between 0.6 – 1.0 m
- Lower layer of gravel with from 3 – 50 mm with depth between 0.1 – 0.45 m

Properties required for medium

- From “Specification for Granular Filter Media” by K J Ives in Effluent and Water Treatment Journal, June 1975 pp 296-305.
- (a) DURABILITY – resistance to abrasion during transport, laying and cleaning. 1% loss per year is a suggested criterion.
- (b) INSOLUBILITY:
- (i) Material should not be lost by dissolving.
- (ii) Toxic substance must not be leached out of medium.
- Test for (i) by immersing in acid and for (ii) by soaking in distilled water and testing for any likely dissolved contaminants.

- c) DENSITY – Is there a tendency to float?
- Can the material be fluidised for back-washing?
- d) SHAPE, sphericity $\psi = d_h / d_s$

- Where d_h is the hydraulic diameter, being the size of a spherenof equal settling velocity to the grain and ds is the mean sieve size.
- Angular particles (low sphericity) are most effective than spherical, but particles for which ψ <0.6 are usually too flat, and cause high headlosses.
- Value of ψ : sphere 1.00
- British filter sand 0.85
- British anthacite 0.7
- e) PREPARATION – Media should be washed and be sieved to a fairly uniform size.
- f) ABILITY TO RETAIN SOLIDS. – The surface chemistry should be tested with a small labratory filter, using the water that the full-scale plant is required to treat.

- Washing will be made when head loss more than 2.5 – 3 m
- Water for backwash is obtained from filtered water.
- Washing time is between 10 -15 minutes for every 24 – 48 hours.
- 3 types of backwashing: using water only, air followed with water, and finally combination of air and water.
- For backwashing air followed with water, the air flow rate used is at 27 – 35 $m^3/hr/m^2$ for 4 minutes and water flow rate is at 45 $m^3/hr/m^2$.

Pressure filter

- Operate at pressure higher than atmospheric thus may required water to be pumped under pressure into the filter if gravitational pressure is low.
- Normally in cylindrical form.
- For practical purpose, maximum diameter for vertical filter is limited to 2.75m and for a horizontal filter with the same diameter with a length of 12m.
- Filtration rate up to 15 m3/m2 per hour.
- Pressure acting on the filter normally less than 80 m head of water.

Pressure filter

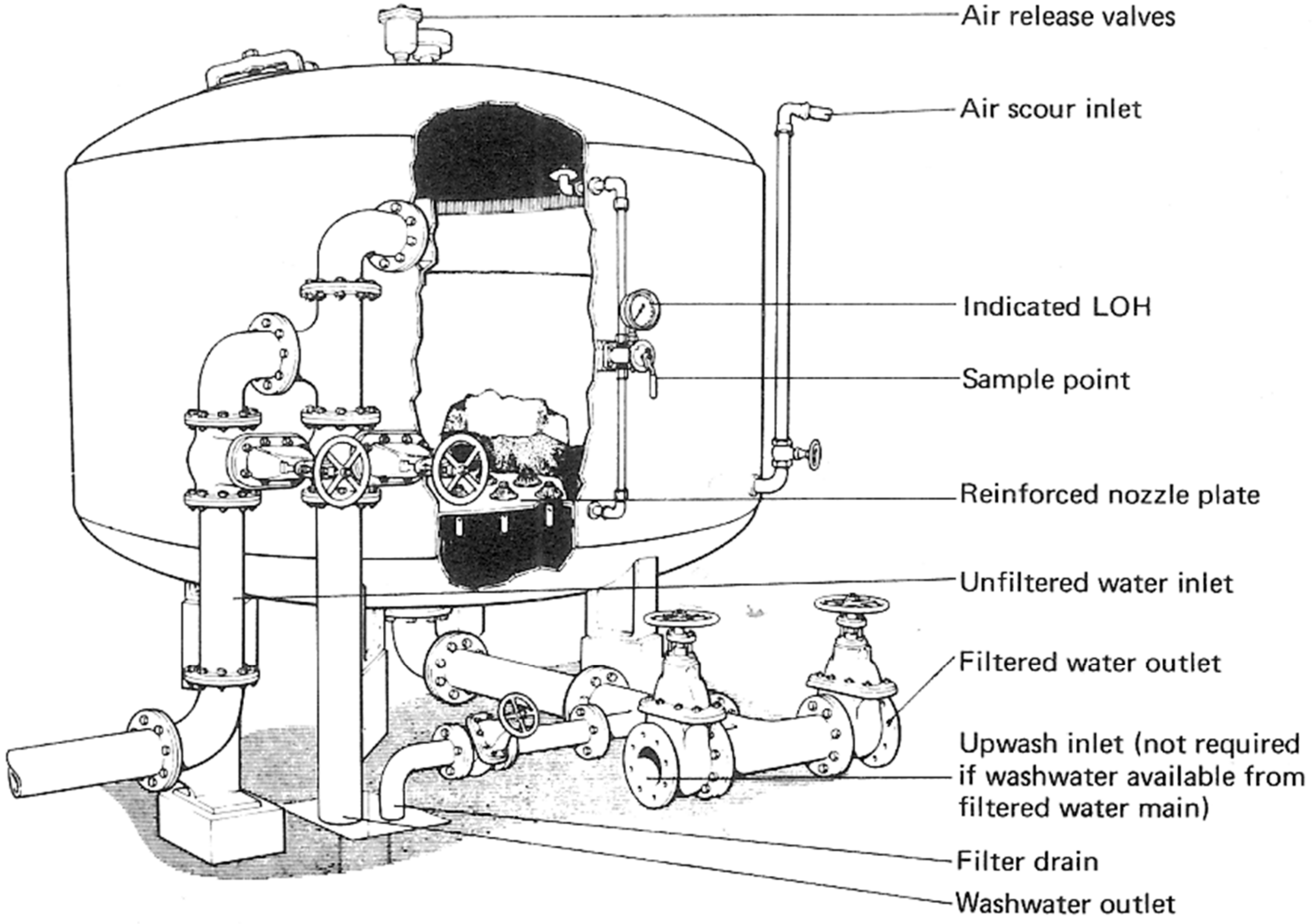


Fig. 7.10 Sectional view of a pressure filter. (Paterson Candy International Ltd.)

ADSORPTION

- Process of collecting soluble substances that are in solution on a suitable interface, between the liquid and a gas, a solid, or another liquid.
- Adsorption is used at the air-liquid interface in the flotation process.
- Only the case of adsorption at the liquid-solid interface will be considered in this discussion.

-------------------ADSORPTION

- Activated-carbon treatment of wastewater is usually thought of as a polishing process for water that has already received normal biological treatment.
- Carbon is used to remove a portion of the remaining dissolved organic matter.

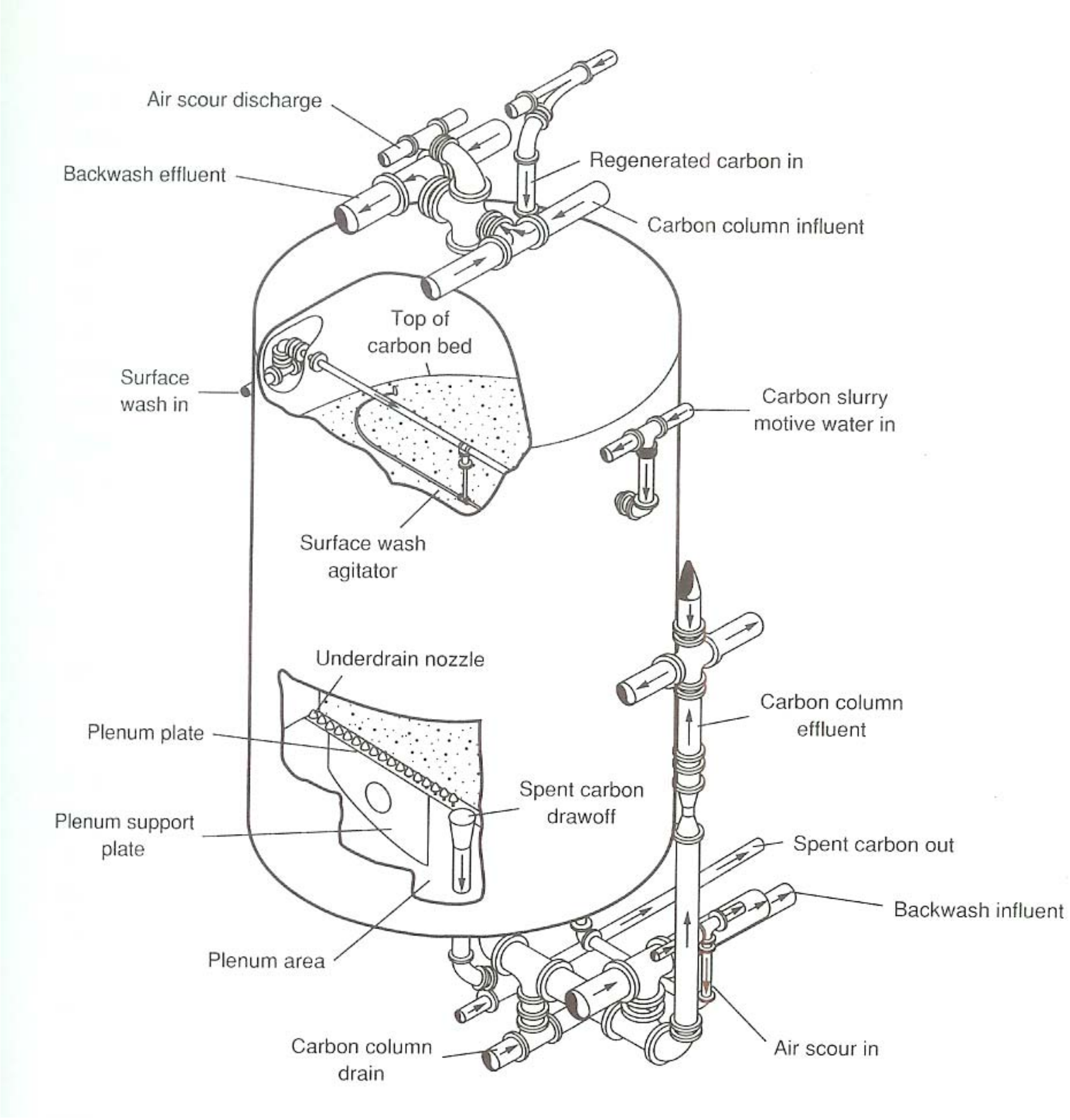
Activated-Carbon and Its Use

- Prepared by first making a char from materials such as almond, coconut, and walnut hulls, other woods, and coal.
- The char is produced by heating the material to a red heat in a retort to drive off the hydrocarbons but with an insufficient supply of air to sustain combustion.
- The char particle is then activated by exposure to an oxidizing gas at high temperature. This gas develops a porous structure in the char and thus creates a large internal surface area. The surface properties that result are a function of both the initial material used and the exact preparation procedure.

-------------Activated-Carbon and Its Use

- After activation, the carbon can be separated into or prepared in different sizes with different adsorption capacities.
- The two size classifications are powdered, which has a diameter of less than 200 mesh, and granular, which has a diameter greater than 0.1 mm.
- A fixed-bed column is often used as a means of contacting wastewater with Granular activated carbon (GAC).
- The water is applied to the top of the column and withdrawn at the bottom. The carbon is held in place with an under-drain system at the bottom of the column.

fixed-bed column



-------------Activated-Carbon and Its Use

- Provision for backwashing and surface washing is usually necessary to limit the head loss buildup due to the removal of particulate material within the carbon column. Fixed-bed columns can be operated singly, in series, or in parallel.
- Expanded-bed and moving-bed carbon contactors have also been developed to overcome the problems associated with head loss. The influent is introduced at the bottom of the column and is allowed to expand, much as a filter bed expands during backwash.

-------------Activated-Carbon and Its Use

- An alternative means of application is that of adding powdered activated carbon (PAC). Powdered activated carbon has been added to the effluent from biological treatment processes, directly to the various biological treatment processes, and in physical-chemical treatment process-flow diagrams. The addition of PAC directly in the aeration basin of an activated-sludge treatment process has proved to be effective in the removal of a number of soluble refractory organics.

Analysis of the Adsorption Process

- Takes place in three steps: **macro-transport**, **micro-transport**, and **sorption**.
- Macro-transport involves the movement of the organic material through the water to the liquid-solid interface by advection and diffusion.
- Micro-transport involves the diffusion of the organic material through the macro-pore system of the GAC to the adsorption sites in the micropores and submicropores of the GAC granule. Adsorption occurs on the surface of the granule and in the macropores and mesopores.

--------Analysis of the Adsorption Process

- Sorption is the term used to describe the attachment of the organic material to the GAC. The term *sorption* is used because it is difficult to differentiate between chemical and physical adsorption.
- The theoretical adsorption capacity of the carbon for a particular contaminant can be determined by calculating its adsorption isotherm.
- The quantity of adsorbate that can be taken up by an adsorbent is a function of both the characteristics and concentration of adsorbate and the temperature.

--------Analysis of the Adsorption Process

- Generally, the amount of material adsorbed is determined **as a function of the concentration** at a constant temperature, and the resulting function is called an ***adsorption isotherm.***
- Equations that are often used to describe the experimental isotherm data were developed by Freundlich, by Langmuir, and by Brunauer, Emmet, and Teller (BET isotherm).
- Of the three, the **Freundlich isotherm** is used most commonly to describe the adsorption characteristics of the activated carbon used in water and wastewater treatment.

Freundlich Isotherm. The empirically derived Freundlich isotherm is defined as follows:

$$\frac{x}{m} = K_f C_e^{1/n} \qquad (1)$$

where, x/m = amount adsorbate adsorbed per unit weight of absorbent (carbon)

Ce =equilibrium concentration of adsorbate in solution after adsorption

K_f ,n = empirical constants.

-------------Freundlich Isotherm

The constants in the Freundlich isotherm can be determined by plotting *(x/m)* versus *C* and making use of Eq. 1 rewritten as:

$$\log\left(\frac{x}{m}\right) = \log K_f + \frac{1}{n}\log C_e \qquad (2)$$

Langmuir Isotherm. Derived from rational considerations, the Langmuir adsorption isotherm is defined as:

$$\frac{x}{m} = \frac{abC_e}{1+bC_e} \qquad \textbf{(3)}$$

where x/m = amount adsorbed per unit weight of adsorbent (carbon)

a, b = empirical constants

Ce = equilibrium concentration of adsorbate in solution after adsorption

------Langmuir Isotherm

- Isotherm was developed by assuming that (l) a fixed number of accessible sites are available on the adsorbent surface, all of which have the same energy and that (2) adsorption is reversible.
- Equilibrium is reached when the rate of adsorption of molecules onto the surface is the same as the rate of desorption of molecules from the surface.

-----------Langmuir Isotherm

- The rate at which adsorption proceeds, is proportional to the driving force, which is the difference between the amount adsorbed at a particular concentration and the amount that can be adsorbed at that concentration. At the equilibrium concentration, this difference is zero.
- Correspondence of experimental data to the Langmuir equation does not mean that the stated assumptions are valid for the particular system being studied because departures from the assumptions can have a canceling effect.

-------------------Langmuir Isotherm

The constants in the Langmuir isotherm can be determined by plotting *C/(x/m)* versus C and making use of Eq. 3 rewritten as

$$\frac{C_e}{(x/m)} = \frac{1}{ab} + \frac{1}{a} C_e \qquad (4)$$

Just Say No To Bottled Water!

Bottled water is over priced, over 95% of cost is bottle, label, lid and transportation.

Bottled water is virtually unregulated, industry lobbyists fight against Federal Purity Regulations every year in Washington... Why?

Bottled water is bad for the environment, Millions of plastic bottles pollute our landfills daily.

Any time water is stored for a prolonged period of time in a plastic bottle, it will take on traces of the chemicals used in the plastic such as Pthylate.

According to the FDA, "Companies that market bottled water as being safer than tap water are defrauding the American public..."

Home water filtration offers significantly higher quality water, at a fraction of the cost and far more convenient than bottled water.

Thank you