Coagulation Processes

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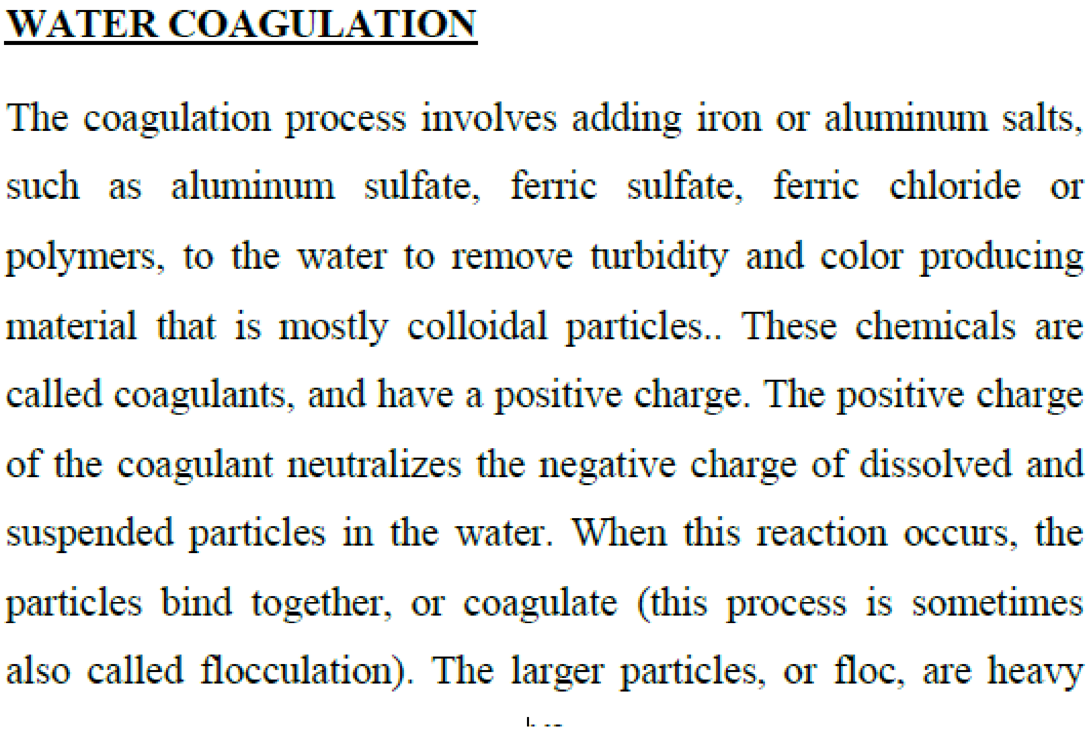
Coagulation:

Agglomeration of particles into groups, increasing the effective size and therefore the settling velocities, is possible in some instances. Particles in the colloidal size range, however, possess certain properties that prevent agglomeration. Surface waters with turbidity resulting from colloidal particles cannot be clarified without special treatment. A knowledge of the nature of colloidal suspensions is essential to this removal.

Coagulation:

Virtually all surface water sources contain perceptible turbidity. Some particle sizes common to most surface waters with different particle diameters, along with their terminal settling velocity (assuming quiescent conditions and specific gravity of 2.65). From the calculated values of settling velocity it is obvious that plain sedimentation will not be very efficient for the smaller suspended particles. Under conditions normally encountered in settling basins, efficient removal of particles less than 50 µm in diameter cannot be expected.

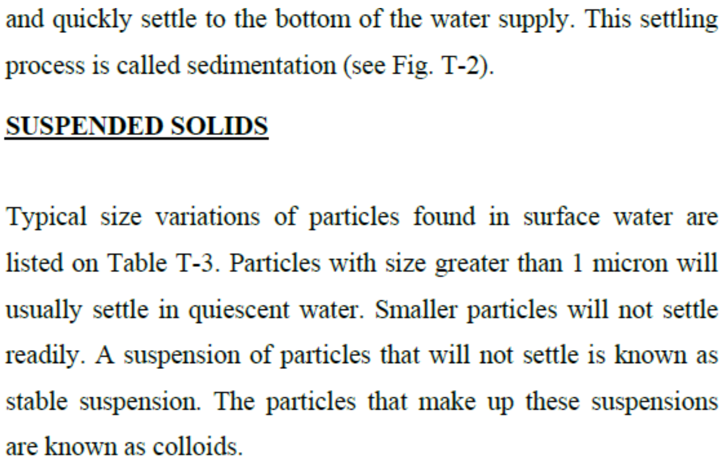
Coagulation:



WATER COAGULATION

The coagulation process involves adding iron or aluminum salts, such as aluminum sulfate, ferric sulfate, ferric chloride or polymers, to the water to remove turbidity and color producing material that is mostly colloidal particles.. These chemicals are called coagulants, and have a positive charge. The positive charge of the coagulant neutralizes the negative charge of dissolved and suspended particles in the water. When this reaction occurs, the particles bind together, or coagulate (this process is sometimes also called flocculation). The larger particles, or floc, are heavy

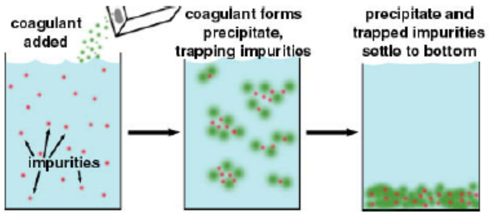
Coagulation:



and quickly settle to the bottom of the water supply. This settling process is called sedimentation (see Fig. T-2).

SUSPENDED SOLIDS

Typical size variations of particles found in surface water are listed on Table T-3. Particles with size greater than 1 micron will usually settle in quiescent water. Smaller particles will not settle readily. A suspension of particles that will not settle is known as stable suspension. The particles that make up these suspensions are known as colloids.



Coagulation:

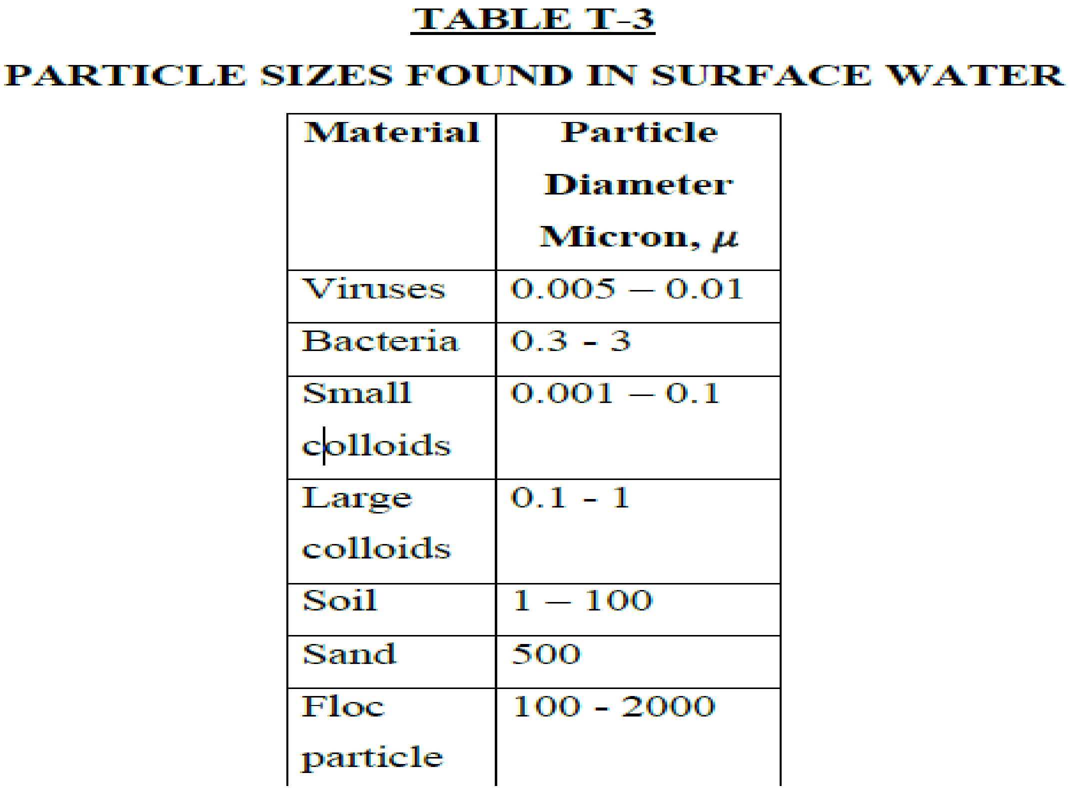
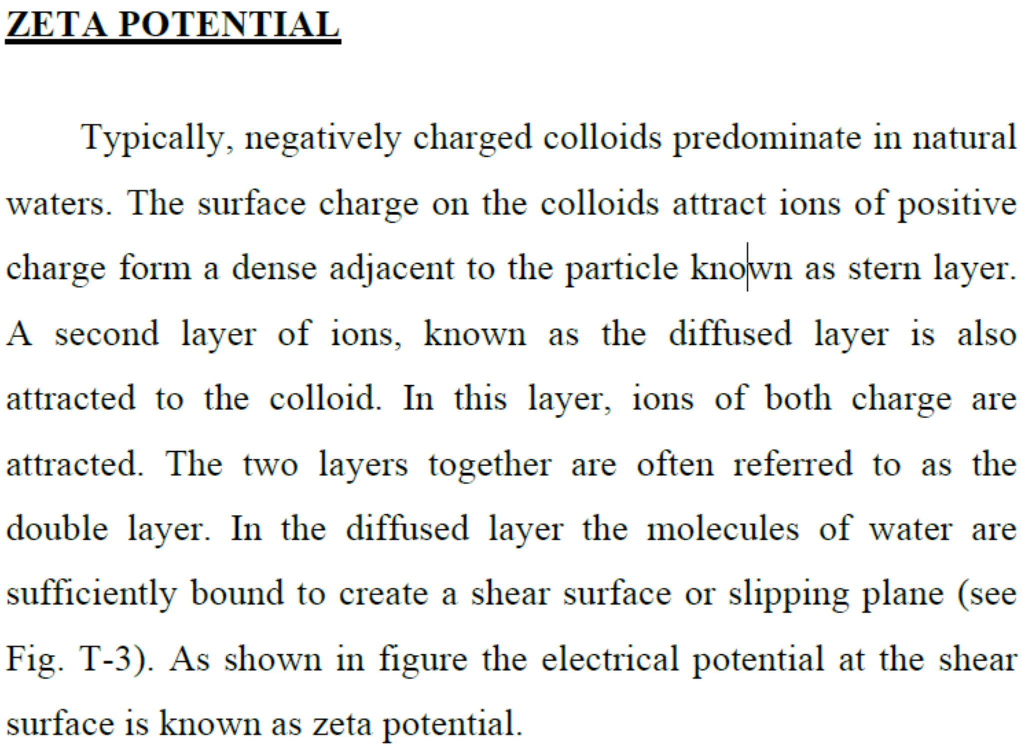


TABLE T-3

PARTICLE SIZES FOUND IN SURFACE WATER

Material	Particle Diameter Micron, μ
Viruses	0.005 – 0.01
Bacteria	0.3 - 3
Small colloids	0.001 – 0.1
Large colloids	0.1 - 1
Soil	1 – 100
Sand	500
Floc particle	100 - 2000

Coagulation:



ZETA POTENTIAL

Typically, negatively charged colloids predominate in natural waters. The surface charge on the colloids attract ions of positive charge form a dense adjacent to the particle known as stern layer. A second layer of ions, known as the diffused layer is also attracted to the colloid. In this layer, ions of both charge are attracted. The two layers together are often referred to as the double layer. In the diffused layer the molecules of water are sufficiently bound to create a shear surface or slipping plane (see Fig. T-3). As shown in figure the electrical potential at the shear surface is known as zeta potential.

Coagulation:

Zeta potential (ζ-potential) is the electric potential difference across the ionic layer around a charged colloid ion, and is one of the fundamental parameters known to affect stability. Typically, the higher the zeta-potential, the more stable the colloid. When the zeta-potential equals zero, the colloid will precipitate into a solid. When the potential is small, attractive forces may exceed this repulsion and the dispersion may break and flocculate. So, colloids with high zeta potential (negative or positive) are electrically stabilized while colloids with low zeta potentials tend to coagulate or flocculate as outlined in the table below.

Coagulation:

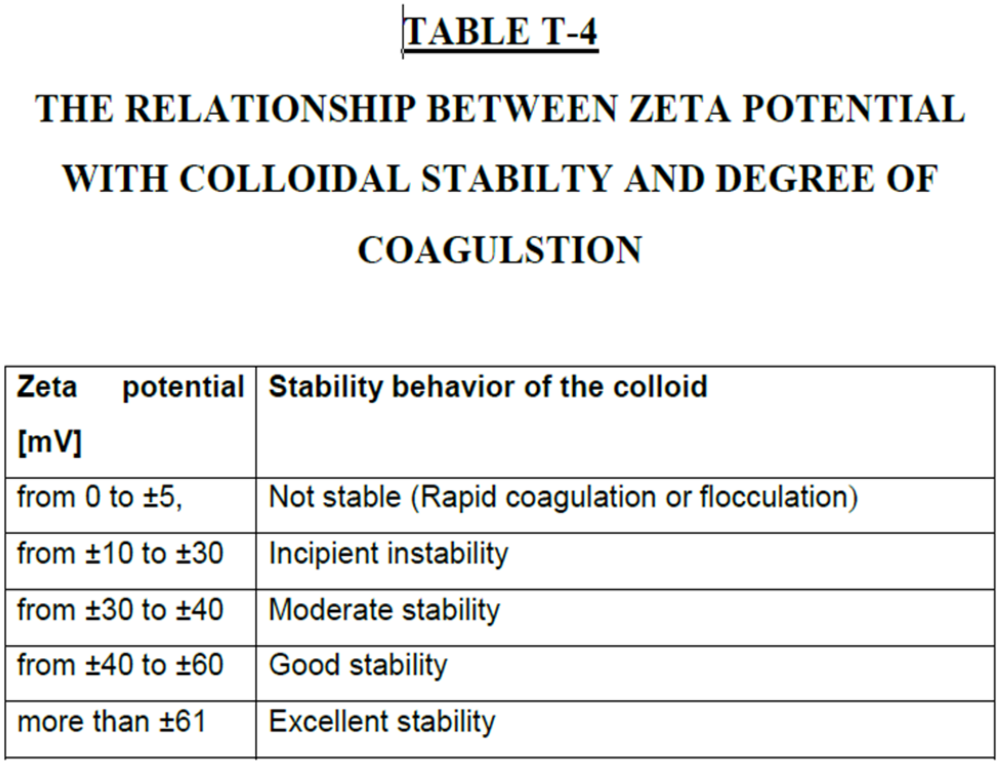


TABLE T-4

THE RELATIONSHIP BETWEEN ZETA POTENTIAL WITH COLLOIDAL STABILTY AND DEGREE OF COAGULSTION

Zeta potential [mV]	**Stability behavior of the colloid**
from 0 to ±5,	Not stable (Rapid coagulation or flocculation)
from ±10 to ±30	Incipient instability
from ±30 to ±40	Moderate stability
from ±40 to ±60	Good stability
more than ±61	Excellent stability

Coagulation:

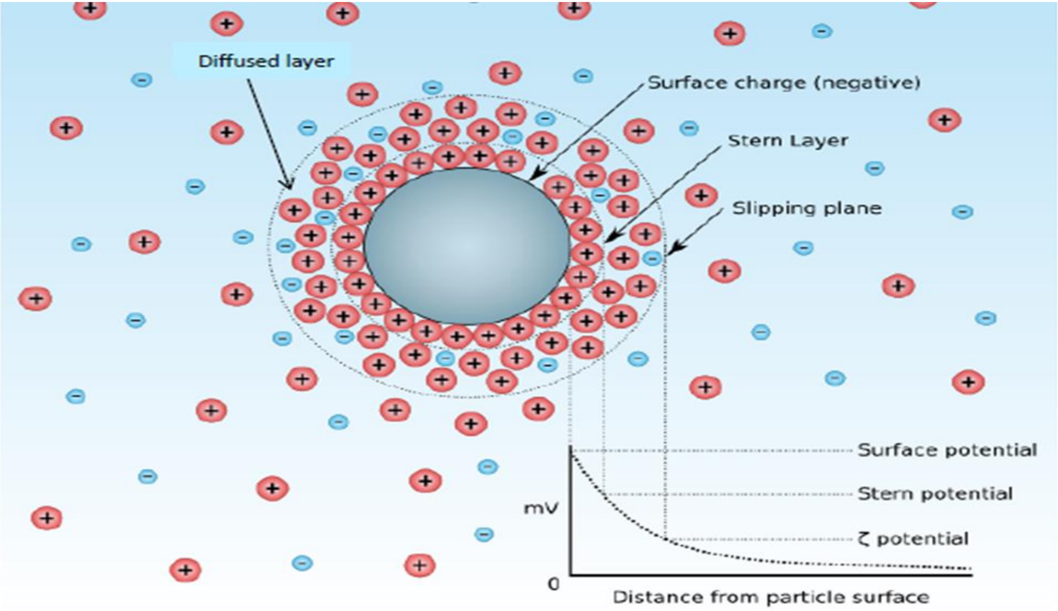
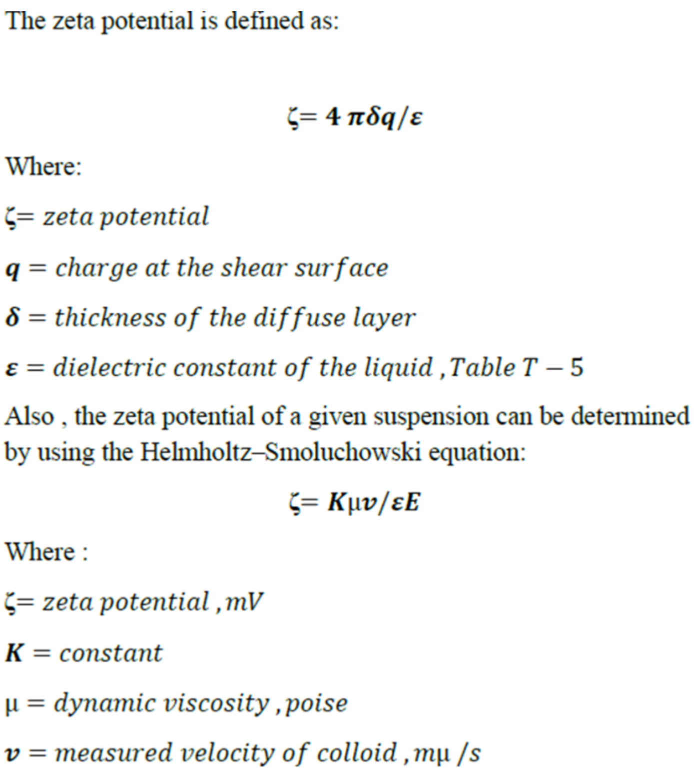


FIGURE T-3

Diagram showing the ionic concentration and potential difference as a function of distance from the charged surface of a particle suspended in a dispersion medium.

Coagulation:



The zeta potential is defined as:

$$\zeta = 4\,\pi\delta q/\varepsilon$$

Where:

ζ = zeta potential

q = charge at the shear surface

δ = thickness of the diffuse layer

ε = dielectric constant of the liquid , Table T − 5

Also , the zeta potential of a given suspension can be determined by using the Helmholtz–Smoluchowski equation:

$$\zeta = K\mu v/\varepsilon E$$

Where :

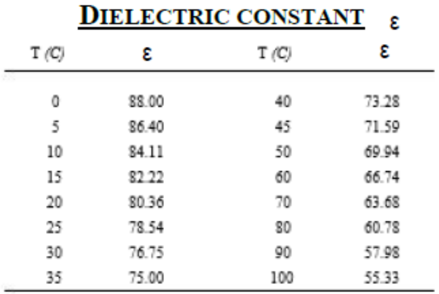
ζ = zeta potential , mV

K = constant

μ = dynamic viscosity , poise

v = measured velocity of colloid , mμ /s

Coagulation:



DIELECTRIC CONSTANT ε

T (C)	ε	T (C)	ε
0	88.00	40	73.28
5	86.40	45	71.59
10	84.11	50	69.94
15	82.22	60	66.74
20	80.36	70	63.68
25	78.54	80	60.78
30	76.75	90	57.98
35	75.00	100	55.33

For practical usage in the determination of the zeta potential, above equation can be re-expressed as :

$$\zeta = \frac{113000}{\varepsilon}\; x\; \mu\; (poise)\; x\; EM\; (\frac{\mu m/s}{V/cm})$$

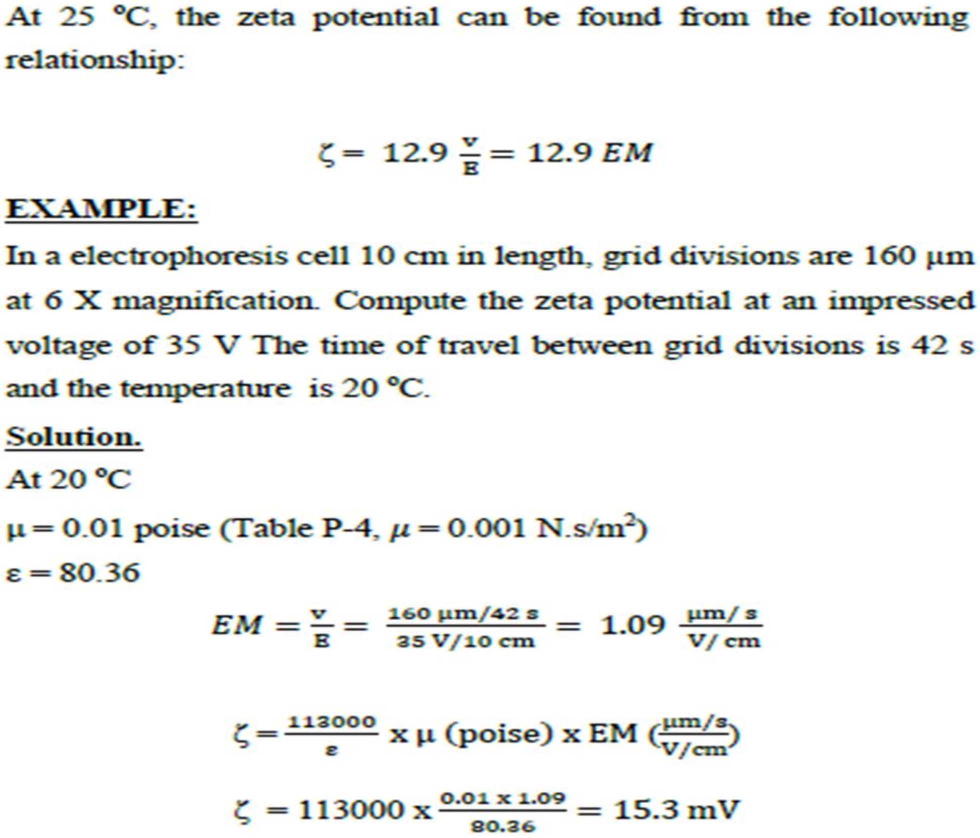
Coagulation:

1 Poise = 1 g/cm/s = 0.1 N·s/m² = 0.1 Pascal ·s

Where:

$EM = \frac{v}{E}$ = electrophoretic mobility, $\left(\frac{\mu m/s}{V/cm}\right)$

Coagulation;



At 25 °C, the zeta potential can be found from the following relationship:

$$\zeta = 12.9\ \frac{v}{E} = 12.9\ EM$$

EXAMPLE:

In a electrophoresis cell 10 cm in length, grid divisions are 160 μm at 6 X magnification. Compute the zeta potential at an impressed voltage of 35 V The time of travel between grid divisions is 42 s and the temperature is 20 °C.

Solution.

At 20 °C

$\mu = 0.01$ poise (Table P-4, $\mu = 0.001$ N.s/m^2)

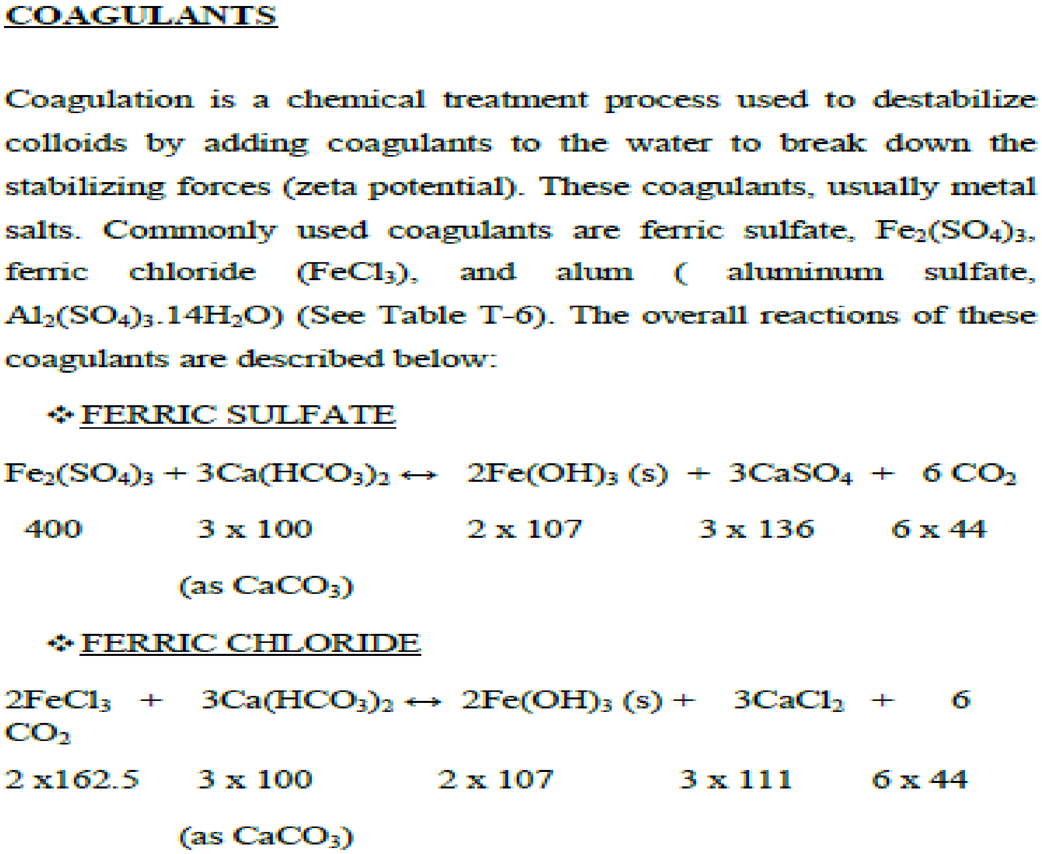
$\varepsilon = 80.36$

$$EM = \frac{v}{E} = \frac{160\ \mu m/42\ s}{35\ V/10\ cm} = 1.09\ \frac{\mu m/s}{V/cm}$$

$$\zeta = \frac{113000}{\varepsilon}\ x\ \mu\ (\text{poise})\ x\ EM\ (\frac{\mu m/s}{V/cm})$$

$$\zeta = 113000\ x\ \frac{0.01\ x\ 1.09}{80.36} = 15.3\ mV$$

Coagulation:



COAGULANTS

Coagulation is a chemical treatment process used to destabilize colloids by adding coagulants to the water to break down the stabilizing forces (zeta potential). These coagulants, usually metal salts. Commonly used coagulants are ferric sulfate, $Fe_2(SO_4)_3$, ferric chloride ($FeCl_3$), and alum (aluminum sulfate, $Al_2(SO_4)_3.14H_2O$) (See Table T-6). The overall reactions of these coagulants are described below:

- **FERRIC SULFATE**

$$Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 \leftrightarrow 2Fe(OH)_3\ (s) + 3CaSO_4 + 6\ CO_2$$

400 3 x 100 2 x 107 3 x 136 6 x 44

(as $CaCO_3$)

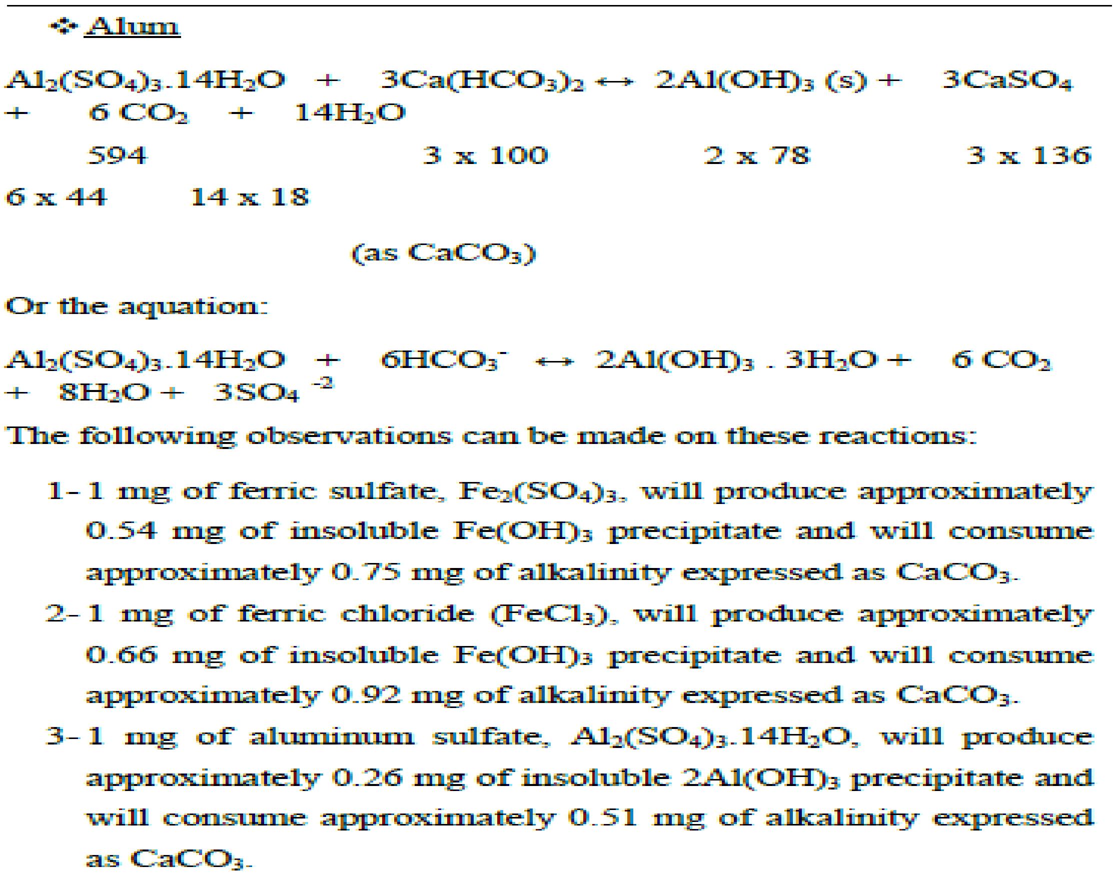
- **FERRIC CHLORIDE**

$$2FeCl_3 + 3Ca(HCO_3)_2 \leftrightarrow 2Fe(OH)_3\ (s) + 3CaCl_2 + 6\ CO_2$$

2 x162.5 3 x 100 2 x 107 3 x 111 6 x 44

(as $CaCO_3$)

Coagulation:



❖ Alum

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

594 3 x 100 2 x 78 3 x 136
6 x 44 14 x 18

(as $CaCO_3$)

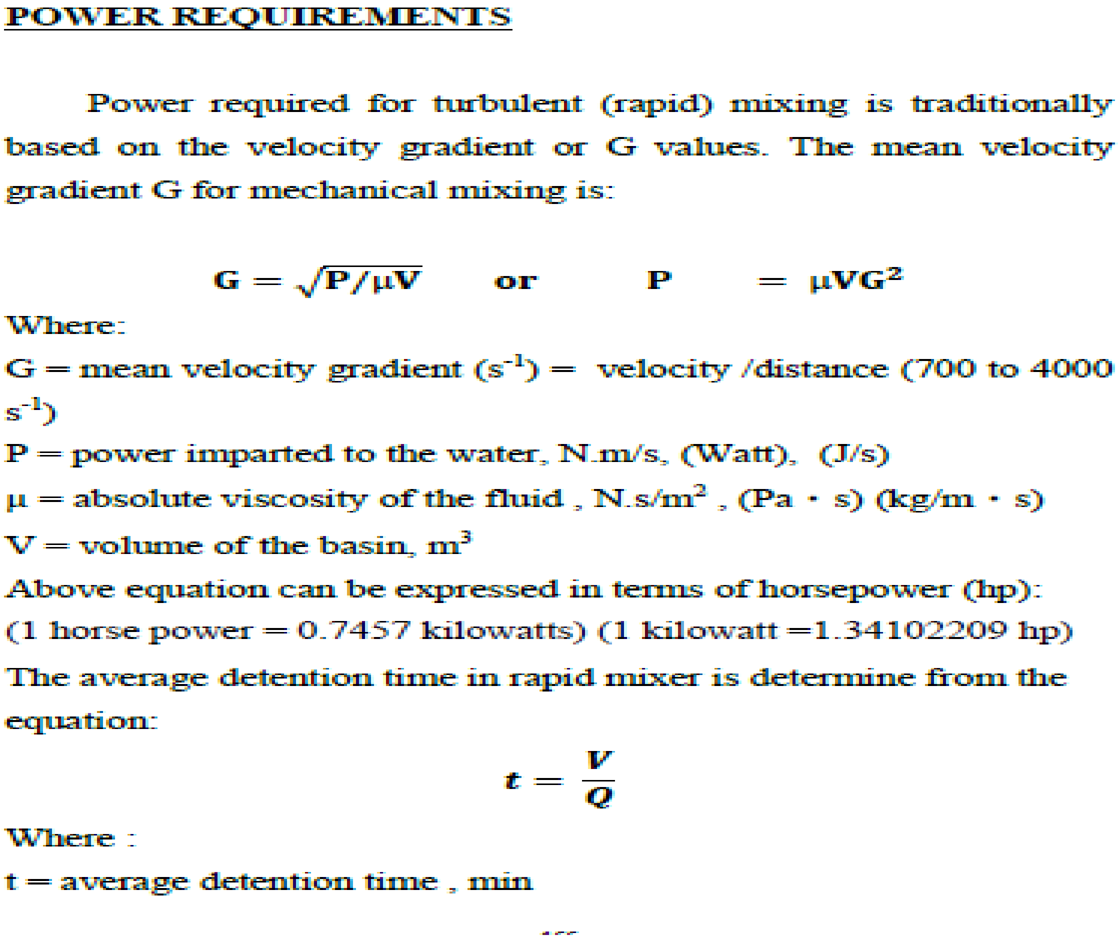
Or the aquation:

$Al_2(SO_4)_3.14H_2O + 6HCO_3^- \leftrightarrow 2Al(OH)_3\ .\ 3H_2O + 6\ CO_2$
$+ 8H_2O + 3SO_4\ ^{-2}$

The following observations can be made on these reactions:

1- 1 mg of ferric sulfate, $Fe_2(SO_4)_3$, will produce approximately 0.54 mg of insoluble $Fe(OH)_3$ precipitate and will consume approximately 0.75 mg of alkalinity expressed as $CaCO_3$.
2- 1 mg of ferric chloride ($FeCl_3$), will produce approximately 0.66 mg of insoluble $Fe(OH)_3$ precipitate and will consume approximately 0.92 mg of alkalinity expressed as $CaCO_3$.
3- 1 mg of aluminum sulfate, $Al_2(SO_4)_3.14H_2O$, will produce approximately 0.26 mg of insoluble $2Al(OH)_3$ precipitate and will consume approximately 0.51 mg of alkalinity expressed as $CaCO_3$.

Coagulation:



POWER REQUIREMENTS

Power required for turbulent (rapid) mixing is traditionally based on the velocity gradient or G values. The mean velocity gradient G for mechanical mixing is:

$$G = \sqrt{P/\mu V} \qquad \text{or} \qquad P = \mu V G^2$$

Where:

G = mean velocity gradient (s^{-1}) = velocity /distance (700 to 4000 s^{-1})

P = power imparted to the water, N.m/s, (Watt), (J/s)

μ = absolute viscosity of the fluid , N.s/m^2 , (Pa · s) (kg/m · s)

V = volume of the basin, m^3

Above equation can be expressed in terms of horsepower (hp):

(1 horse power = 0.7457 kilowatts) (1 kilowatt =1.34102209 hp)

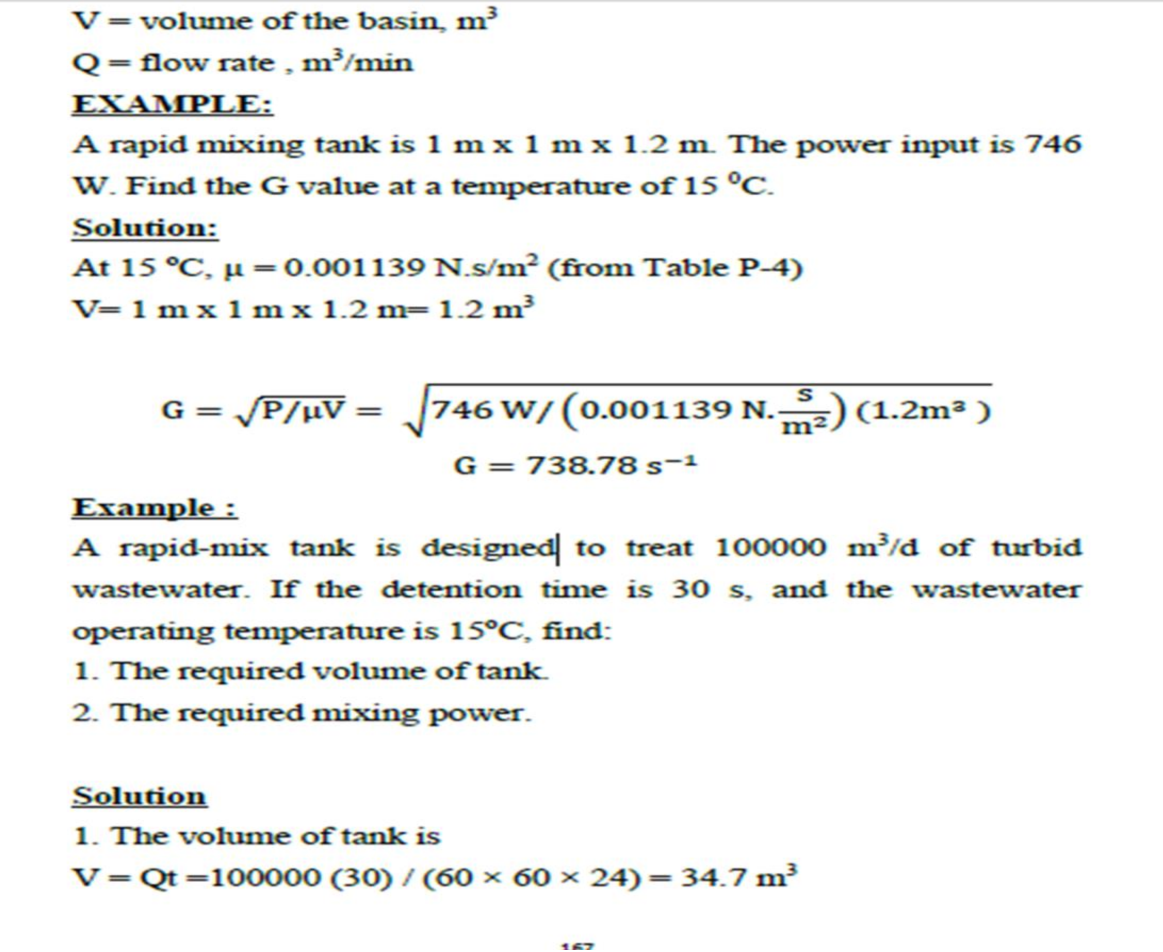
The average detention time in rapid mixer is determine from the equation:

$$t = \frac{V}{Q}$$

Where :

t = average detention time , min

Coagulation:



V = volume of the basin, m^3

Q = flow rate , m^3/min

EXAMPLE:

A rapid mixing tank is 1 m x 1 m x 1.2 m. The power input is 746 W. Find the G value at a temperature of 15 °C.

Solution:

At 15 °C, $\mu = 0.001139\ N.s/m^2$ (from Table P-4)

$V = 1\ m \times 1\ m \times 1.2\ m = 1.2\ m^3$

$$G = \sqrt{P/\mu V} = \sqrt{746\ W/\left(0.001139\ N.\frac{s}{m^2}\right)(1.2m^3)}$$

$$G = 738.78\ s^{-1}$$

Example :

A rapid-mix tank is designed to treat 100000 m^3/d of turbid wastewater. If the detention time is 30 s, and the wastewater operating temperature is 15°C, find:

1. The required volume of tank.
2. The required mixing power.

Solution

1. The volume of tank is

$V = Qt = 100000\ (30) / (60 \times 60 \times 24) = 34.7\ m^3$

Coagulation:

The power, P, is given by:

$$\mathbf{G = \sqrt{\frac{P}{\mu V}} \quad or \quad P = \mu V G^2}$$

(From Table -4)

At 15°C , $\mu = 1.139 \times 10^{-3}$ kg/m.s

(From Table T-6)

The value of G for $t = 30$ s is 900 s^{-1}.

$$P = \mu V G^2 = (1.139 \times 10^{-3})(34.7)(900)^2$$

$$= 32014 \text{ N.m / s}$$

$$= 32014 \text{ W} = 32 \text{ kW} , \text{ Since } 1 \text{ hp} = 745.7 \text{ W:}$$

$$P = 32014 / 745.7 = 43 \text{ hp}$$

Coagulation Processes

A large portion of the suspended particles in water are sufficiently small that their removal in a sedimentation tank is impossible at reasonable surface overflow rate .

Colloidal particles , as a result of their small size , have a very large ratio of surface area to volume . most colloidal particle in water are negatively charged . the surface charge on colloidal particles is the major contributor to their long – term stability . particles which might otherwise settle or coalesce are mutually repelled by their like charge . coagulation is a chemical technique directed toward destabilization of colloidal particles . flocculation , in engineering usage . is a slow mixing technique which promotes the agglomeration of destabilized particles . the coagulation involves the addition of chemical . the processes are very complex , but may be described as follows :

Ca

Coagulation Processes

Most of the metallic coagulants react with water to produce free hydrogen ions . since nearly off natural water contain alkalinity , the hydrogen ion s released will react with this ,reducing the variation in PH . if a water contains insufficient alkalinity ,the addition of a metallic coagulant may depress the PH below the range in which the particular salt is effective . In such circumstances , an alkaline salt must be added to increase the buffer capacity of the solution . the adequacy of the alkalinity can be estimated from the folloing simplified equations , which reorient the approximate overall reactions.

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

Calcium hydroxide increases the water alkalinity

Ca

Aluminum swfate (alum):

$Al_2\,(so_4)_3\,.\,18\,H_2O + 3Ca(OH)_2$

$$Al_2\,(so_4)_3\,.\,18\,H_2O + 3Ca(OH)_2 \longrightarrow \underbrace{2Al\,(OH)_3}_{\text{FLOC SETTLE}} + \underbrace{3Ca\,So_4}_{\text{CAUSES HARDNESS}} + 18H_2O$$

The case of addition of <u>soda ash or sodium carbonate</u> ($Na_2\,Co_3$) to increase water alkalinity , the alum reaction can be described by the fallowing equation :

$$Al2\,(So_4)_3\,.18H_2O + 3Na_2Co_3 + 3H_2O \longrightarrow 2Al\,(OH)_3 + 3Na_2\,SO_4 + 18H_2O + 3CO_2$$

Ferric chloride :

$$Fe\,SO_4 \rightarrow .7H_2O + Ca(OH)_2 \quad Fe\,(OH)_2 + Ca\,So_4 \quad \text{or} \quad 2Fe\,Cl_3 \rightarrow + 3Ca\,(HCo_3)_2$$

$$+3CaCl_2 + 6CO_2$$

Ca

Coagulation Processes

Ferric sulfate:

$Fe\ (So_4)_3 + 3Ca(HCO_3)_2 \qquad 2Fe\ (OH)_3 + 3CaSo_4 + 6CO_2$

Ferrous sulfate and lime

$Fe\ So_4\ 7H_2O + Ca(OH)_2 \longrightarrow Fe\ (OH)_2 + Ca\ So_4 + 7H_2O$

The chemicals commonly used in coagulation include alum (aluminum sulfate), ferric chloride , ferric sulfate , sodium aluminates', poly aluminum chloride , the most commonly coagulant used . the alum is acidic material needs to alkaline environment to increase reaction .
The optimum chemical dosage produces a maximum mean particle size , a minimum cont of small particles , and minimum turbidity prior to settling . dosages which are substantially too high or too low will be ineffective and may, in fact, produce colloidal suspensions of the coagulant it self . the optimum PH range for alum is between 4.0 to 7.0 .

Coagulation Processes

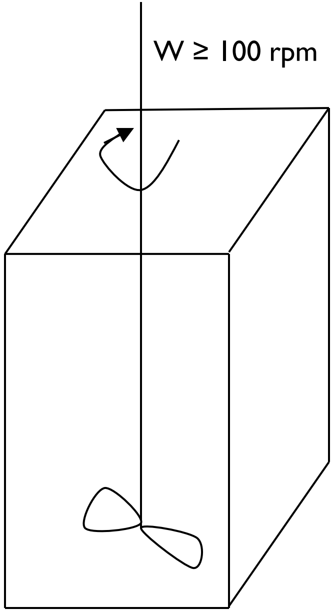
Design criteria of design of coagulation or flash mixing tank :

1-Depth = (2-3)m

2-detention time = 10 – 20 sec or 30 – 60 sec , max = 1 min .

3-L= (1.50 -20) w

4-w (revolution speed) ≥ 100 r.p.m



Ex: design a flash mixing tank (coagulation tank) to treat flow rate of 0.10 m^3/s.

Solution :- use rectangular tank

$V = Q * t$

Let t = 1min :. $V = 1 * 60 * 0.10 = 6\ m^3$ let $D = 2.50$ m

$As = 6/2.5 = 2.40\ m^2$

Let $l = 2w$

$2\ w^2 \Longrightarrow$ w≈1.1 m :. L 2.20 m

Ca

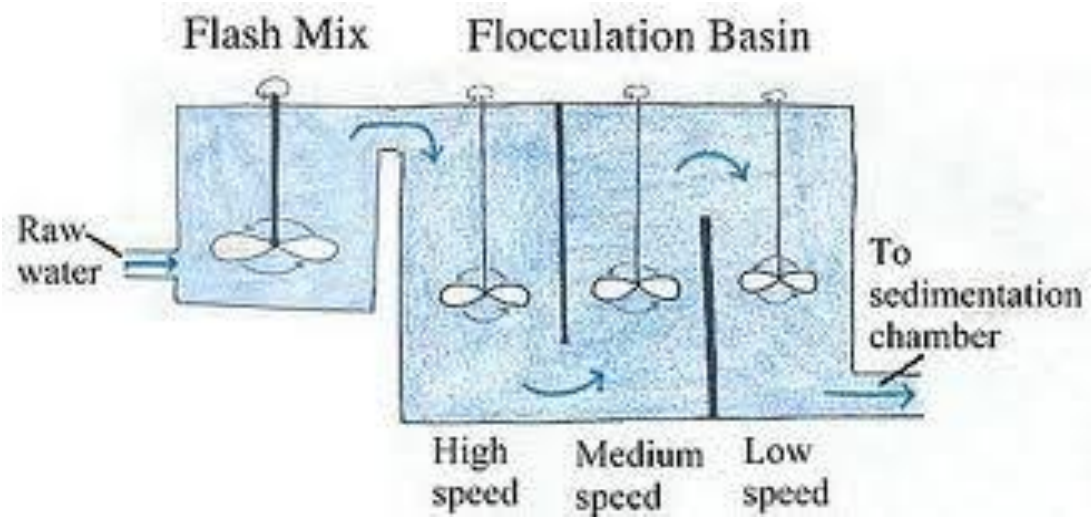
or in case of using of squared tank

$2.4 = L^2$:. $L = 1.55$ m

Or in case of using of circular tank

$$2.4 = \frac{\pi \, Dia^2}{4}$$

:. Dia ≈ 1.75 m



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Coagulation

Ex:

design a flash mixing tank (coagulation tank) if Q = 0.10 m ^{3}/sec.

sol .

V = Q *t let t = 1 min .

V = 1 * 60 * 0.1 = 6 m^3 .

Let D = 2.5 m (2-3)m .

As * D = 6 m^3 :.As = 6 / 2.5 = 2.40 m^2

L = (1.5 – 2) W

So , let L = 2W

:. 2.40 = 2W^2 :. W^2 = 1.2 W ≈ 1.10 m L = 9.20 m (rectangular tank)

*IF squared tank (L = w)

2.4 = L * L = L^2 :. L = 1.55 M

*If circular tank :. 2.40 = ΠD^2/4 :. D ≈1.75 m

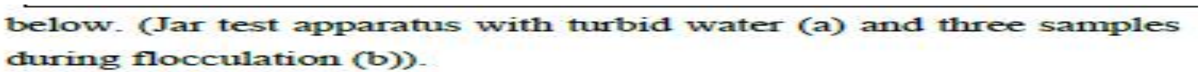
* It is recommended that the dosage of coagulant is may be(30 – 70) mg /l and thus related to water c

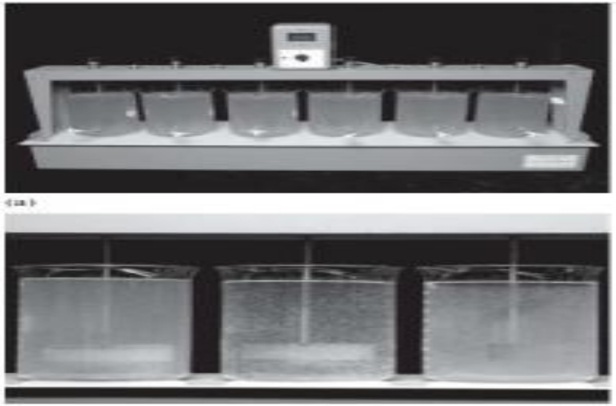
Coagulation:

JAR TEST

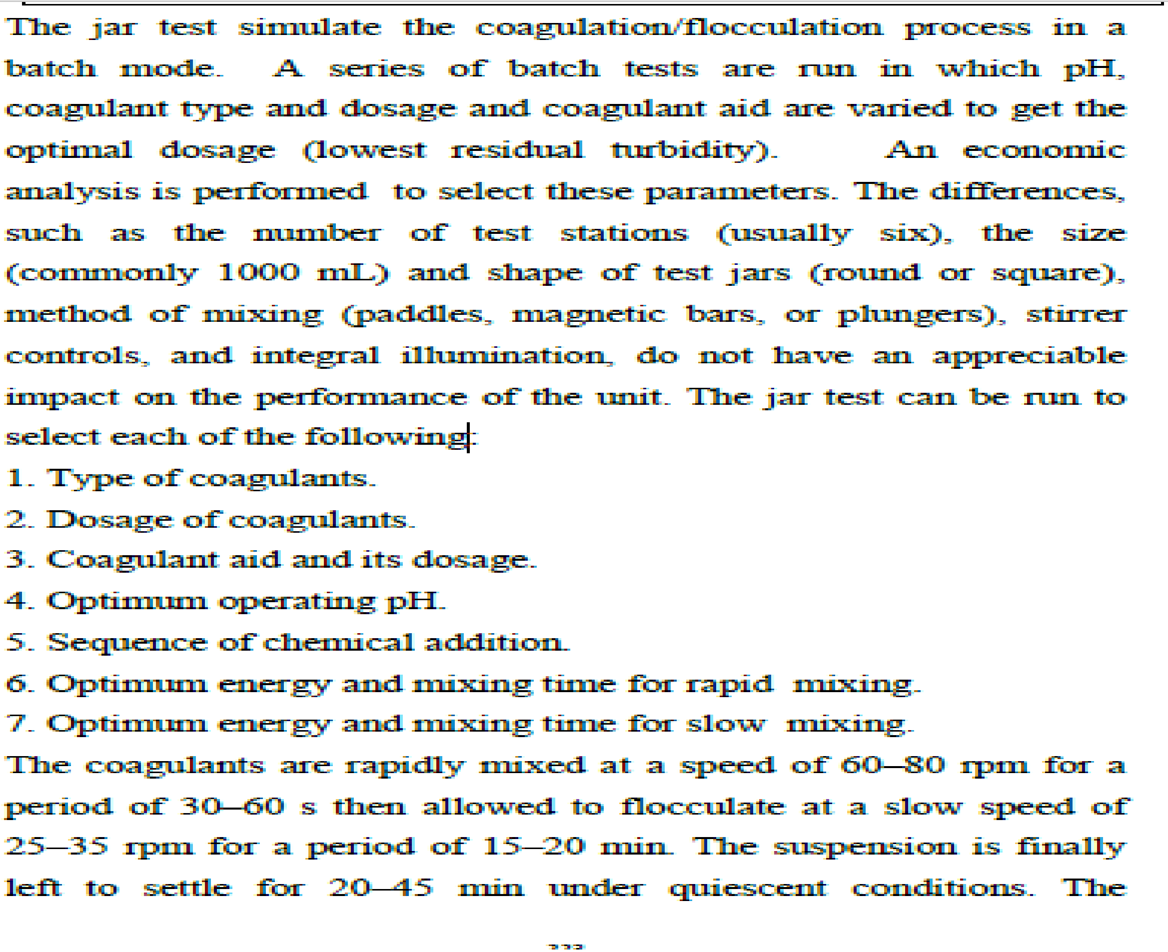
Because of the number and complexity of coagulant reactions, the actual dose and pH for a given water on a given day is generally determined empirically from a laboratory test. The test procedure is called a "jar test" based on the configuration of the test apparatus. An actual gang-stirrer apparatus is shown in the figures

Coagulation:


below. (Jar test apparatus with turbid water (a) and three samples during flocculation (b)).



Coagulation:



The jar test simulate the coagulation/flocculation process in a batch mode. A series of batch tests are run in which pH, coagulant type and dosage and coagulant aid are varied to get the optimal dosage (lowest residual turbidity). An economic analysis is performed to select these parameters. The differences, such as the number of test stations (usually six), the size (commonly 1000 mL) and shape of test jars (round or square), method of mixing (paddles, magnetic bars, or plungers), stirrer controls, and integral illumination, do not have an appreciable impact on the performance of the unit. The jar test can be run to select each of the following:

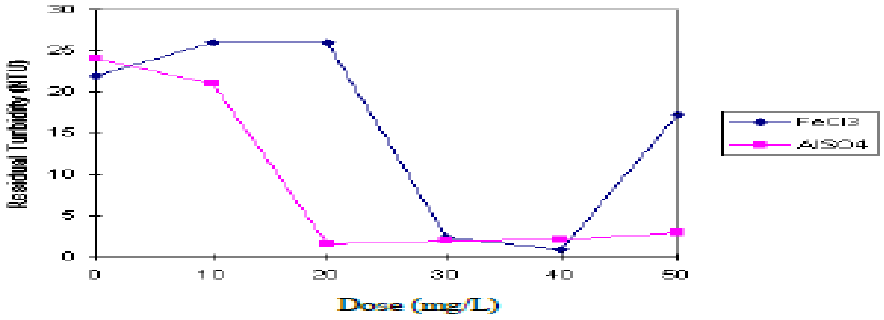
1. Type of coagulants.
2. Dosage of coagulants.
3. Coagulant aid and its dosage.
4. Optimum operating pH.
5. Sequence of chemical addition.
6. Optimum energy and mixing time for rapid mixing.
7. Optimum energy and mixing time for slow mixing.

The coagulants are rapidly mixed at a speed of 60–80 rpm for a period of 30–60 s then allowed to flocculate at a slow speed of 25–35 rpm for a period of 15–20 min. The suspension is finally left to settle for 20–45 min under quiescent conditions. The

Coagulation:

appearance and size of the floc, the time for floc formation, and the settling characteristics are noted. The supernatant samples are drawn off from each sample and analyzed for turbidity, color, suspended solids, and pH. With this information in hand, the optimum chemical dosage is selected on the basis of best effluent quality and minimum coagulant cost. pH.

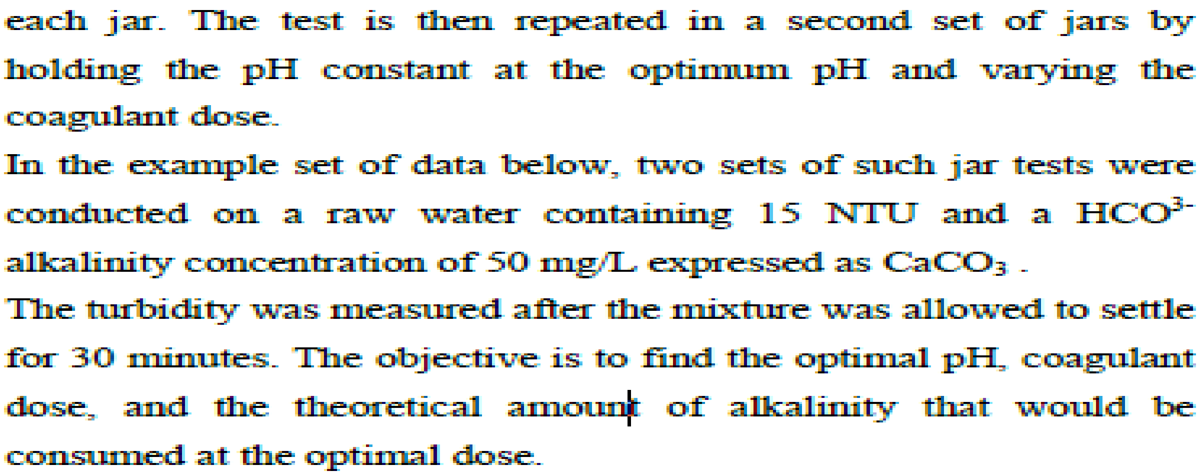
Typical results from a jar test series might look like:



Example

Six beakers are filled with the raw water, and then each is mixed and flocculated uniformly by identical paddle stirrers driven by a single motor (a gang stirrer). A typical test is conducted by first dosing each jar with the same alum dose and varying the pH in

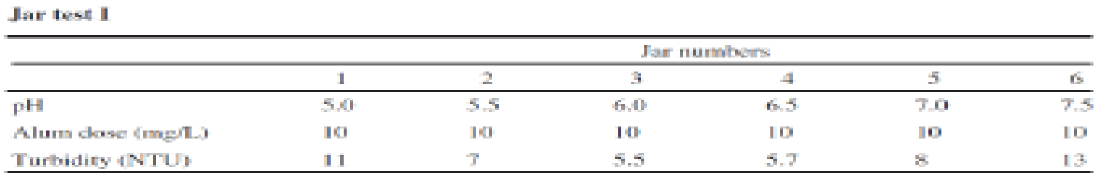
Coagulation:



each jar. The test is then repeated in a second set of jars by holding the pH constant at the optimum pH and varying the coagulant dose.

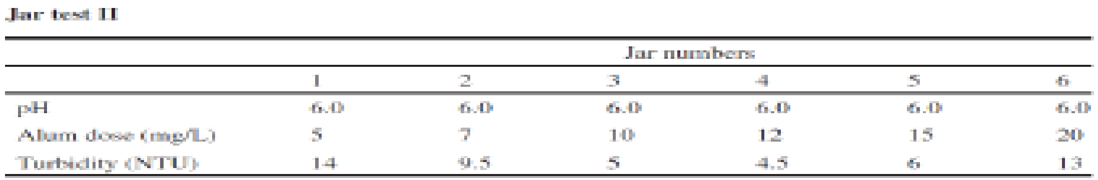
In the example set of data below, two sets of such jar tests were conducted on a raw water containing 15 NTU and a HCO^{3-} alkalinity concentration of 50 mg/L expressed as $CaCO_3$.

The turbidity was measured after the mixture was allowed to settle for 30 minutes. The objective is to find the optimal pH, coagulant dose, and the theoretical amount of alkalinity that would be consumed at the optimal dose.



Jar test I

	Jar numbers					
	1	2	3	4	5	6
pH	5.0	5.5	6.0	6.5	7.0	7.5
Alum dose (mg/L)	10	10	10	10	10	10
Turbidity (NTU)	11	7	5.5	5.7	8	13



Jar test II

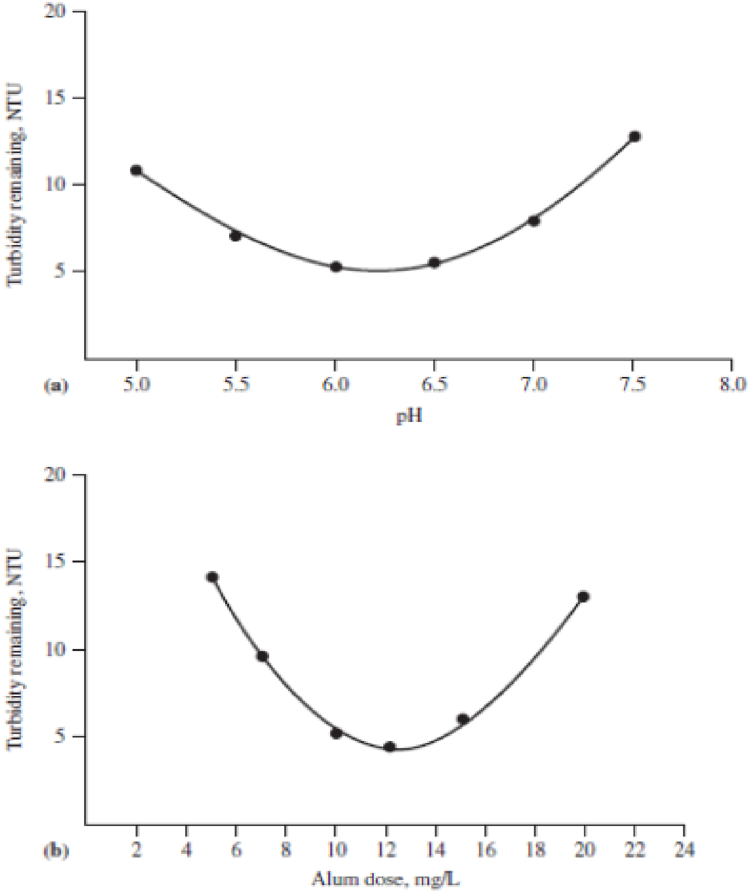
	Jar numbers					
	1	2	3	4	5	6
pH	6.0	6.0	6.0	6.0	6.0	6.0
Alum dose (mg/L)	5	7	10	12	15	20
Turbidity (NTU)	14	9.5	5	4.5	6	13

Coagulation:

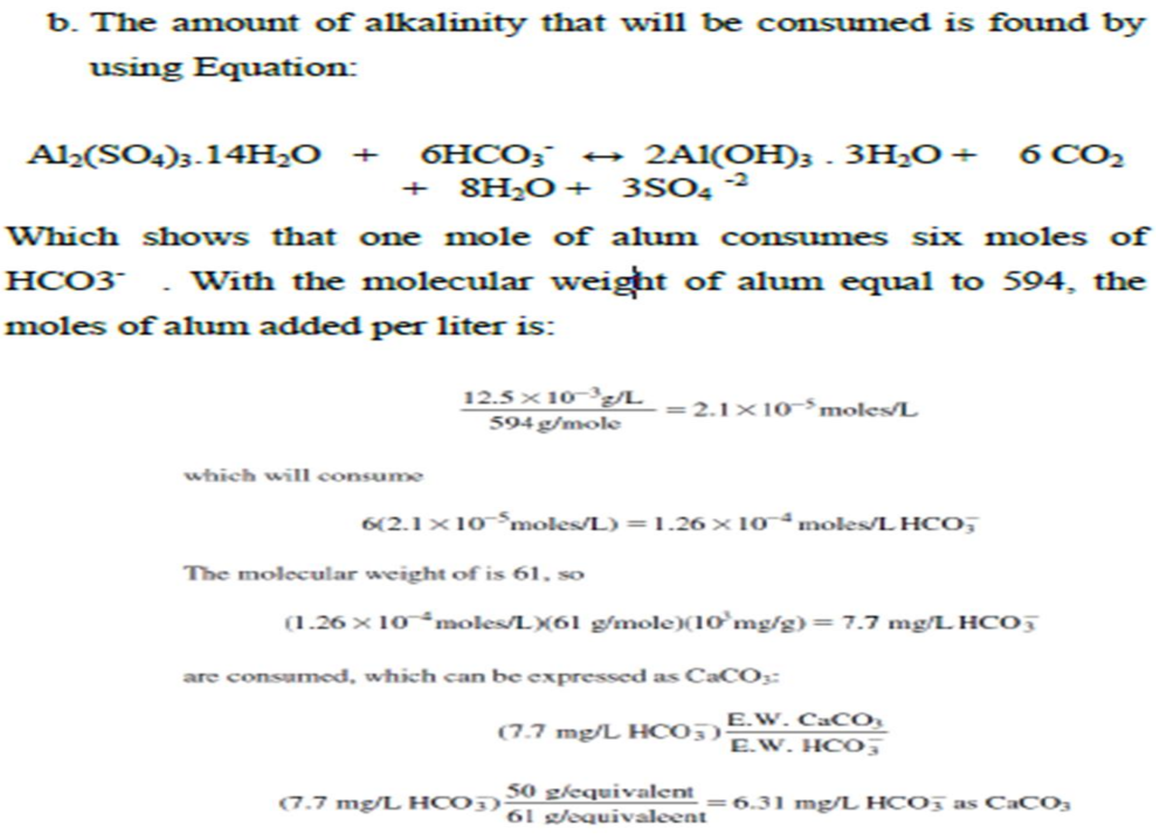
Solution:

a. The results of the two jar tests are plotted as shown in in Figures. In the first test, the optimal pH was chosen as 6.0, and this pH was used for the second jar test. From the second jar test, the optimal alum dose was estimated to be about 12.5 mg/L. In actual practice, the laboratory technician would probably try to repeat the test using a pH of 6.25 and varying the alum dose between 10 and 15 to pinpoint the optimal conditions. From Figures, the optimum pH was estimated to be 6.0 and the optimum dose was estimated to be 12.5 mg/L.

Coagulation:



Coagulation:



b. The amount of alkalinity that will be consumed is found by using Equation:

$$Al_2(SO_4)_3.14H_2O \;+\; 6HCO_3^- \leftrightarrow 2Al(OH)_3\,.\,3H_2O + 6\,CO_2 + 8H_2O + 3SO_4^{\,-2}$$

Which shows that one mole of alum consumes six moles of $HCO3^-$. With the molecular weight of alum equal to 594, the moles of alum added per liter is:

$$\frac{12.5\times10^{-3}\text{g/L}}{594\,\text{g/mole}} = 2.1\times10^{-5}\,\text{moles/L}$$

which will consume

$$6(2.1\times10^{-5}\text{moles/L}) = 1.26\times10^{-4}\,\text{moles/L}\,HCO_3^-$$

The molecular weight of is 61, so

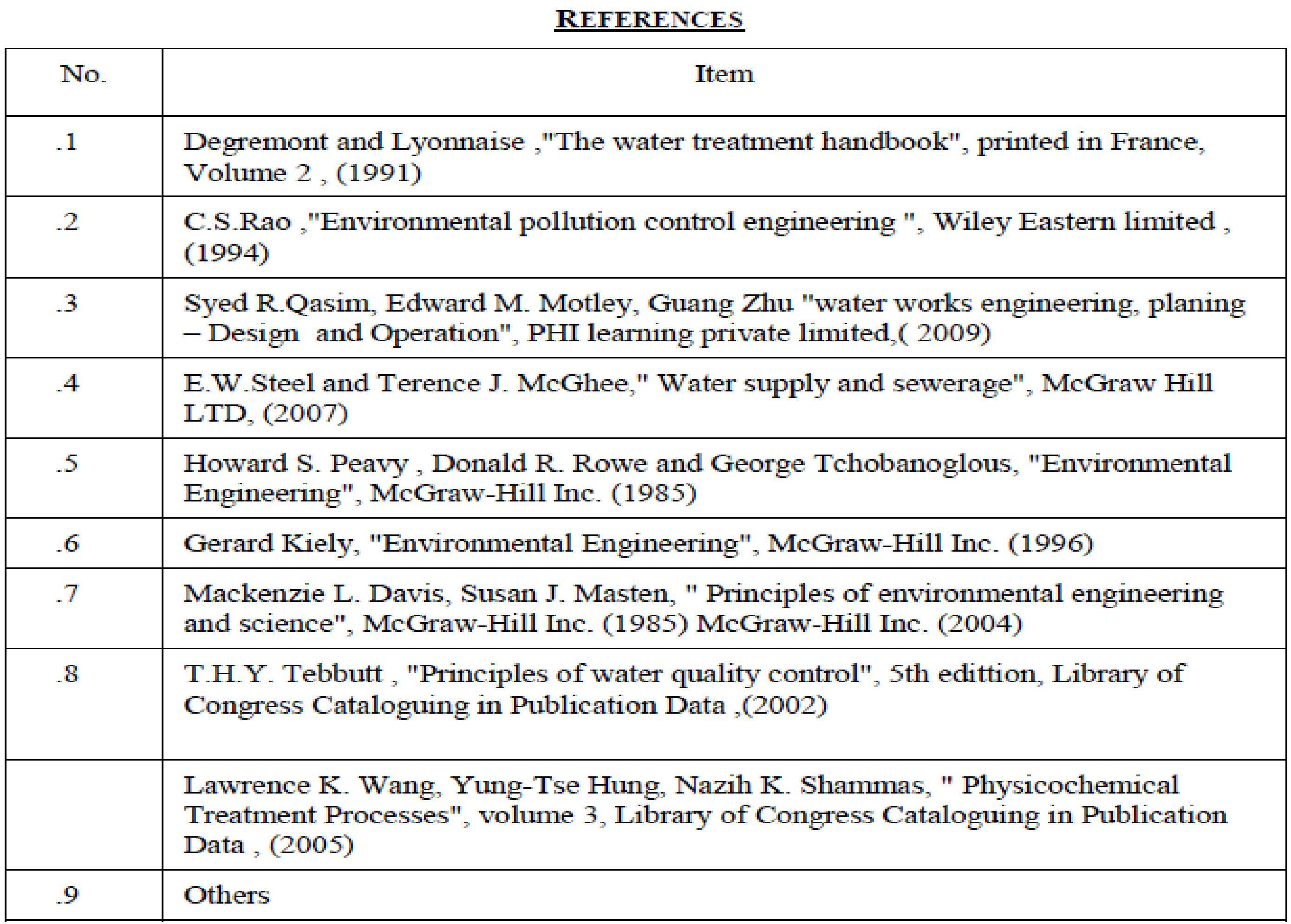
$$(1.26\times10^{-4}\text{moles/L})(61\ \text{g/mole})(10^3\text{mg/g}) = 7.7\ \text{mg/L}\,HCO_3^-$$

are consumed, which can be expressed as $CaCO_3$:

$$(7.7\ \text{mg/L}\ HCO_3^-)\frac{\text{E.W. }CaCO_3}{\text{E.W. }HCO_3^-}$$

$$(7.7\ \text{mg/L}\ HCO_3^-)\frac{50\ \text{g/equivalent}}{61\ \text{g/equivaleent}} = 6.31\ \text{mg/L}\ HCO_3^-\ \text{as}\ CaCO_3$$

References:



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For listening