(ii) to collect information for location of an industry, its future expansion, availability of labour, marketing and distribution of the product, etc.;

(iii) to provide data to the transportation industry;

(iv) to work out requirements for other public utilities such as telephones, electric power, etc.

Following are various methods of population forecasts or population projections and the selection of method will naturally depend on the available data:

(1) Arithmetical increase method
(2) Geometrical increase method
(3) Incremental increase method
(4) Graphical method
(5) Comparative method
(6) Zoning method
(7) Ratio and correlation method
(8) Growth composition analysis method
(9) Logistic curve method.

A brief description of each of the above method of forecasting population will now follow:

(1) *Arithmetical increase method:* In this method, the average increase of population for the last *three* or *four* decades is worked out and then for each successive future decade, this average is added. This method gives low results and it is to be adopted for large cities which have practically reached their maximum development.

Problem 2-3.

The census records of a city show population as follows:

Present	50000
Before one decade	47100
Before two decades	43500
Before three decades	41000.

Work out the probable population after *one*, *two* and *three* decades by using arithmetical increase method.

Solution:

The average increase of population between successive decades upto present is worked out as follows:

Present and first decades = 50000 − 47100 = 2900
First and second decades = 47100 − 43500 = 3600
Second and third decades = 43500 − 41000 = 2500
Total 9000

Average increase per decade $= \frac{9000}{3} = 3000.$

The population after each successive future decade is obtained by adding this average as follows:

Population after *one* decade = 50000 + 3000 = 53000
Population after *two* decades = 53000 + 3000 = 56000
Population after *three* decades = 56000 + 3000 = 59000.

---

(2) ***Geometrical increase method:*** In this method, it is assumed that the percentage increase in population from decade to decade remains constant. From the available census records, this percentage is fixed and then population of each future successive decade is worked out. The fixation of percentage in case of developing cities should be done carefully. Otherwise this method is likely to give very high results. This method gives better results for old cities which are not undergoing further development.

As the increase in population is compounded over the existing population every decade, this method is sometime also referred to as the *uniform increase method.*

The assumed average growth rate can be computed in the following *two* ways:

(i) *Arithmetic average:* The average of the percentage growth rates of the several known decades of the past are worked out and then, by taking the arithmetic mean, the constant increase per decade is obtained. Let a_1, a_2, a_3, etc. be the percentage increase in population from decade to decade.

Then, $$a = \frac{a_1 + a_2 + a_3 + \dots\dots}{n}$$

where a = arithmetic average
n = number of decades.

(ii) *Geometric average:* In this method, the average growth rate is obtained by the geometric average as follows:

$$a = \sqrt[n]{a_1 \times a_2 \times a_3 \times \dots\dots}$$

Problem 2-4.

Work out problem 2-3 by using the geometrical increase method.

Solution:

(1) *By arithmetic average:* The percentage increase in population from decade to decade is worked out as follows:

Present and first decades $= \frac{50000 - 47000}{47100} \times 100 = 6.16$

First and second decades $= \frac{47100 - 43500}{43500} \times 100 = 8.28$

Second and third decades $= \frac{43500 - 41000}{41000} \times 100 = 6.10$

Total 20.54

∴ Average percentage $= \frac{20.54}{3} = 6.85$, say 7.

The population after each successive future decade is obtained by adding this percentage increase as follows:

Population after *one* decade $= 50000 + 50000 \times 0.07 = 53500$

Population after *two* decades $= 53500 + 53500 \times 0.07 = 57245$

Population after *three* decades $= 57245 + 57245 \times 0.07 = 61252.$

(2) *By geometric average:* In this case,

Average population $= \sqrt[3]{6.16 \times 8.28 \times 6.10}$

$= \sqrt[3]{311.13}$

$= 6.78$, say 7.

Hence the population after each successive future decade will be same as above.

(3) *Incremental increase method:* This method combines the above *two* methods. The population of each successive future decade is first worked out by the arithmetical increase method and to these values, the incremental average per decade is added. It thus combines the advantages of both the above methods and hence it gives satisfactory results.

Problem 2-5.

Work out problem 2-3 by using the incremental increase method.

Solution:

The incremental increase between successive decades is worked out as follows:

Period	Increase of population	Incremental increase
Second and third decades	2500	
		+ 1100
First and second decades	3600	
		− 700
Present and first decades	2900	
		Net + 400

∴ Average incremental increase $= \frac{400}{2} = 200.$

Average arithmetical increase as worked out in problem 3 $\Big\} = 3000.$

The population after each successive future decade is obtained by adding arithmetical increase and this average incremental increase as follows:

Population after *one* decade $= 50000 + 3000 + (1 \times 200)$
$= 53200$

Population after *two* decades $= 53200 + 3000 + (2 \times 200)$
$= 56600$

Population after *three* decades $= 56600 + 3000 + (3 \times 200)$
$= 60200$

(4) *Graphical method:* In this method, a curve of population against time is drawn for the city under consideration. The known census records are put up on the graph to get the shape of the curve. The curve is then carefully extended from present to future decades and the population after each successive future decade is read from the curve. The extension of curve in future decades should be based on personal judgement of the designer and it should be assisted by probable future conditions and past history of the city.

It may be noted that graphical method indicates the graphic representation of previous mathematical methods. The nature of extension will determine the mathematical method.

Problem 2-6.

Work out problem 2-3 by using the graphical method.

Solution:

The population in thousands is plotted against decades as shown in fig. 2-2. The population after each successive future decade is obtained by extending the curve, shown by dotted line in fig. 2-2.

The curve of cost in Rs. (million) per unit of storage against height of dam is drawn as shown in fig. 3-26 and it indicates that the most economic height of dam with respect to the construction cost only is 70 m.

Problem 3-3.

Calculate the discharge of a tube well of diameter 80 cm. The thickness of water bearing strata and drawdown are respectively 10 m and 4 m. Assume the radius of circle of influence as 300 m and permeability as 20 m^3 per unit area per day.

Solution:

$$Q = \frac{\pi P\,(H^2 - h^2)}{2.303 \log_{10} \frac{R}{r}}$$

In the given problem,

$P = 20$ m^3 per unit area per day

$H = 10$ m

$H - h = 4$ m

or $h = H - 4 = 10 - 4 = 6$ m

$R = 300$ m

$r = 40$ m.

Substituting,
$$Q = \frac{\pi \times 20 \times (10^2 - 6^2)}{2.303 \times \log_{10} \frac{300}{0.40}}$$
$$= \frac{\pi \times 20 \times 16 \times 4}{2.303 \times 2.8751}$$
$= 607.30$ m^3 per day.

Problem 3-4.

The diameter of a tube well is 50 cm. It is constructed in an aquifer of thickness 14 m. The radius of circle of influence is 225 m. Assuming permeability as 30 m^3 per unit area per day, calculate the drawdown when the yield of well is 1900 m^3 per day.

Solution:

$$Q = \frac{\pi P\,(H^2 - h^2)}{2.303 \log_{10} \frac{R}{r}}$$

In the given problem:

$Q = 1900$ m^3 per day

$P = 30$ m^3 per unit area per day

$H = 14$ m

$R = 225$ m

$r = 25$ cm.

Substituting,
$$1900 = \frac{\pi \times 30 \times (14^2 - h^2)}{2.303 \log_{10} \frac{225}{0.25}}$$

$$\therefore \quad 1900 \times 2.303 \times 2.4771 = \pi \times 30\,(14^2 - h^2)$$
$$\therefore \quad 115 = 14^2 - h^2$$
$$\therefore \quad h^2 = 81$$
$$\therefore \quad h = 9 \text{ m}$$
$$\therefore \quad \text{Drawdown} = (H - h) = 14 - 9 = 5 \text{ m.}$$

Problem 3-5.

In a recuperation test, the following results were obtained:

Initial depression head = 8 m

Final depression head = 5 m

Time of recuperation = 2 hours

Diameter of well = 4 m.

Calculate the specific capacity of well and yield under a head of 3 m.

Solution:

$$K = 2.303\,\frac{A}{T}\log\frac{H_1}{H_2}$$

In the given problem,

$$A = \frac{\pi \times 4^2}{4} = 4\pi \text{ m}^2$$

$T = 2$ hours

$H_1 = 8$ m

$H_2 = 5$ m.

Substituting, $K = 2.303\,\frac{4\pi}{2}\log\frac{8}{5}$

$= 2.95$ m^3 per hour under the head of one metre.

Then, $Q = K.H$

$= 2.95 \times 3 = 8.85$ m^3 per hour.

Problem 3-6.

Find the diameter of an open well to give a yield of 360 litres per minute. The working depression head is 4 m and the aquifer soil consists of coarse sand.

Solution:

$$Q = \left(\frac{K}{A}\right) A.H.$$

In the given problem,

Q = Yield of well in m^3 per hour

$$= \frac{360 \times 60}{1000} = 21.6 \text{ m}^3 \text{ per hour}$$

$\frac{K}{A}$ = 1 for coarse sand expressed in m^3 per hour per m^2 of area of well under one metre depression head

$A = \frac{\pi d^2}{4}$ where d is the diameter of well in m

H = 4 m.

Substituting,

$$21.6 = 1 \times \frac{\pi d^2}{4} \times 4$$

$$\therefore \quad d^2 = \frac{21.6}{\pi} = 6.88$$

$$\therefore \quad d = 2.62 \text{ m, say } 2.70 \text{ m.}$$

Problem 3-7.

From the following data, work out the most economical size of tube well:

Yield of well	: 7200 m^3 per day
Thickness of confined aquifer	: 30 m
Radius of circle of influence	: 300 m
Drawdown	: 5 m
Permeability	: 60 m^3 per unit area per day.

Solution:

$$Q = \frac{2.72\,Pt\,(H-h)}{\log \frac{R}{r}}$$

In the given problem,

Q = 7200 m^3 per day

P = 60 m^3 per unit area per day

t = 30 m

$(H - h)$ = 5 m

R = 300 m.

Substituting,

$$7200 = \frac{2.72 \times 60 \times 30 \times 5}{\log \frac{300}{r}}$$

$$\therefore \quad \log \frac{300}{r} = 3.40 \quad \therefore \frac{300}{r} = 2512$$

$$\therefore \quad r = \frac{300}{2512} \times 100 = 11.94 \text{ cm, say } 120 \text{ mm.}$$

Problem 3-8.

A tube well having diameter of 20 cm taps an artesian aquifer of thickness 25 m. If drawdown is 4.50 m and permeability is 40 m^3 per unit area per day, calculate the yield of tube well in litres per hour. Assume the radius of circle of influence as 300 m.

Solution:

$$Q = \frac{2.72\,Pt\,(H-h)}{\log \frac{R}{r}}$$

In the given problem,

P = 40 m^3 per unit area per day

t = 25 m

$(H - h)$ = 4.5 m

R = 300 m

$r = \frac{10}{100} = 0.10$ m.

Substituting,

$$Q = \frac{2.72 \times 40 \times 25 \times 4.5}{\log \frac{300}{0.10}}$$

$$= \frac{12240}{3.4771} = 3520.17 \text{ m}^3 \text{ per day}$$

$$= \frac{3520.17}{24} \times 1000$$

$$= 146673.75, \text{ say } 147700 \text{ litres per hour.}$$

Power for pumps:

Following machines are used to develop power for the working of pumps:

(1) Steam engine
(2) Diesel engine
(3) Gasoline engine
(4) Electric motor.

Each of the above machine will now be briefly described.

(1) ***Steam engine:*** The steam engine is clumsy and old fashioned. It is practically out of date at present. It consumes more fuel and takes more time to come to the working stage. Also there is considerable loss of energy when it is being stopped for cooling. It is however reliable and can be used for large installations where fuel is cheaply available. The efficiency of steam engine is about 60% to 70%.

(2) ***Diesel engine:*** The initial cost of this type of engine is high and it produces noise during working. It requires skilled supervision. The engine is not so clumsy as steam engine and it takes up the load at once. It is reliable and consumes less quantity of fuel. The efficiency of diesel engine is about 70% to 80%.

(3) ***Gasoline engine:*** In this type of engine, the gasoline or petrol is used as fuel. It is therefore very costly and hence it is rarely adopted. It is suitable for working as stand-by units of pumps.

(4) ***Electric motor:*** This is the modern machine to create power for pumps and it is used for small and medium plants. The motor is compact in design and can be switched on immediately. It runs smoothly and it is free from dust and smoke. It is found to be cheap at places where electricity can be developed economically. However, in case of sudden failure of electric plant, the whole system of water supply comes to a standstill and causes great hardship. Hence it is advisable to keep diesel engines or gasoline engines as stand-by units along with electric motors. The efficiency of electric motors is about 90% to 95%.

The above are the *four* machines which are adopted for developing power for the pumps and depending upon the facilities, fund, design, nature of pump, etc., a suitable machine is recommended.

Horse-power of pumps:

The horse-power required for the pumps is worked out as follows:

Let W = weight of water in kg per second
H = total head in m.

Then, $\text{H.P.} = \dfrac{WH}{75}$.

This is known as the *water horse-power* or W.H.P. and the brake horse-power or B.H.P. is obtained by dividing W.H.P. with the efficiency of pump and motor.

Let E = combined efficiency of pump and motor.

Then, $\text{B.H.P.} = \dfrac{WH}{75E}$.

In this equation, the value of H is obtained by the following equation:

$$H = h + h_f$$

where h = total static head or difference in level between the lowest water level in the well and full supply level of the tank
h_f = head lost in friction.

Let f = Coefficient of friction
l = Length of pipe in m
v = Velocity of flow in m per second
g = Acceleration due to gravity = 9.81 m/sec^2
d = Diameter of pipe in m
Q = Discharge in m^3 per second.

Then, $Q = \dfrac{\pi d^2}{4} \cdot v$

or $v = \dfrac{4Q}{\pi d^2}$.

Then, according to the modified Darcy-Weibach formula,

$$h_f = \frac{flv^2}{2gd} = \frac{fl}{2 \times 9.81 \times d} \times \left(\frac{4Q}{\pi d^2}\right)^2$$

$$= \frac{flQ^2}{12.1\, d^5}.$$

Note: In working out the total head, the loss of head due to friction only is considered as other minor losses of head are generally negligible.

Problem 4-1.

A city has a population of 60000. It is to be supplied with water at 250 litres per head per day. Calculate the B.H.P. of motor to raise the water to an overhead tank 60 m high. The length and diameter of the rising main are 300 m and 30 cm respectively. The efficiency of motor is 95% and that of pump is 60%. Assume $f = 0.04$ and peak hour demand as 1.50 times the average demand.

Solution:

$$
\begin{aligned}
\text{Average demand} &= 60000 \times 250\\
&= 15000000 \text{ litres per day}\\
&= 15000 \text{ m}^3 \text{ per day}\\
&= \frac{15000}{24 \times 60 \times 60} \text{ m}^3 \text{ per second}\\
&= 0.1736 \text{ m}^3 \text{ per second.}\\
\text{Peak hour demand} &= 1.50 \times 0.1736\\
&= 0.26 \text{ m}^3 \text{ per second.}
\end{aligned}
$$

$$
\begin{aligned}
\therefore \quad W &= 1000 \times 0.26 = 260 \text{ kg per second}\\
h &= 60 \text{ m}\\
h_f &= \frac{flQ^2}{12.1 d^5}\\
&= \frac{0.04 \times 300 \times (0.26)^2}{12.1 \times (0.30)^5} = 27.82 \text{ m}\\
H &= h + h_f\\
&= 60.00 + 27.82 = 87.82 \text{ m}\\
E &= 0.95 \times 0.60 = 0.57.
\end{aligned}
$$

Hence,

$$
\begin{aligned}
\text{B.H.P.} &= \frac{WH}{75E}\\
&= \frac{260 \times 87.82}{75 \times 0.57}\\
&= 534.
\end{aligned}
$$

Problem 4-2.

Design a pumping station to raise water from an intake well to a sedimentation tank with the following data:

Water to be raised per day = 18000 m^3
Length of suction pipe = 40 m
Length of rising main = 150 m
Coefficient of friction = 0.04
Diameter of pipe (suction and rising) = 50 cm
Shifts of working of pumps = 2
Duration of each shift = 8 hours
Combined efficiency of motor and pump = 80%
Static head through which water is to be raised

Solution:

Water requirement per day = 18000 m^3
Total pumping hours = 2 × 8 = 16.

$$\text{Required pumping capacity per hour} = \frac{18000}{16} = 1125 \text{ m}^3.$$

Note: Since requirement of water per day is 18000 m^3 and the pumps are to work only for 16 hours per day, the required pumping capacity per hour is obtained by dividing daily requirement by 16 and not by 24.

$$
\begin{aligned}
Q \text{ per second} &= \frac{1125}{60 \times 60} = 0.31 \text{ m}^3 \text{ per second}\\
W &= 1000 \times 0.31 = 310 \text{ kg per second}\\
h &= 21 \text{ m}\\
h_f &= \frac{flQ^2}{12.1 . d^5} = \frac{0.04 \times (40 + 150) \times (0.31)^2}{12.1 \times (0.50)^5}\\
&= 1.95 \text{ m}\\
H &= h + h_f = 21 + 1.95 = 22.95 \text{ m}\\
E &= 0.80.
\end{aligned}
$$

Hence,

$$
\begin{aligned}
\text{B.H.P.} &= \frac{WH}{75E}\\
&= \frac{310 \times 22.95}{75 \times 0.80} = 118.60.
\end{aligned}
$$

Provide 4 units of pumps, each having B.H.P. of 30. Thus the total B.H.P. would be 120. Provide 2 such other additional units of pumps as stand-by units.

Problem 4-3.

The water is to be pumped from a jack well to the service reservoir situated 2 km away. Work out the capacity of pumps and motors from the following data:

Water to be raised per day = 8000 m^3
Total hours of pumping = 16
R.L. of water level in jack well = 322.00
R.L. of F.S.L. of reservoir = 342.00
Depression in water level during pumping = 1.50 m
Friction in rising main = 1 m per km length
Other losses of head due to bends, valves, etc. = 1 m
Combined efficiency of pump and motor = 63%.

Solution:

Water to be raised per day $= 8000 \text{ m}^3$

Total pumping hours $= 16$

Required pumping capacity per hour $= \dfrac{8000}{16} = 500 \text{ m}^3.$

$$Q = \frac{500}{60 \times 60} = 0.14 \text{ m}^3 \text{ per second}$$

$$W = 1000 \times 0.14 = 140 \text{ kg per second}$$

$$h = (342 - 322) + \text{depression head}$$

$$= 20 + 1.50 = 21.50 \text{ m}$$

$$h_f = 1 \times 2 = 2 \text{ m.}$$

$$\text{Other losses} = 1 \text{ m}$$

$$H = h + h_f + \text{other losses}$$

$$= 21.50 + 2 + 1 = 24.50 \text{ m}$$

$$E = 0.63.$$

$$\text{Hence,} \quad \text{B.H.P.} = \frac{WH}{75E}$$

$$= \frac{140 \times 24.50}{75 \times 0.63}$$

$$= 72.59.$$

Adopt 2 pumps of 40 B.H.P. each together with one stand-by unit of the same capacity.

Problem 4-4.

The water is to be raised from a tube well to an overhead storage tank. Work out the B.H.P. of the electro-motor pumping set from the following data:

Discharge of tube well = 30 litres per second
Length of rising main = 200 m
Coefficient of friction = 0.072
R.L. of ground level = 200.00
R.L. of water level in the well = 192.00
Depression head = 5 m
R.L. of water level in overhead tank = 215.00
Combined efficiency of electro-pumping set = 75%
Velocity in rising main

Solution:

$$Q = \frac{\pi d^2}{4} \times v$$

where

Q = discharge

$= 0.03 \text{ m}^3$ per second

d = diameter of rising main

v = velocity

$= 180$ cm per second.

$$\therefore \quad 0.03 = \frac{\pi d^2}{4} \times 1.80$$

$$\therefore \quad d = \sqrt{\frac{4 \times 0.03}{\pi \times 1.80}}$$

$$= 0.1456 \text{ m, say } 0.15 \text{ m.}$$

$$W = 1000 \times 0.03 = 30 \text{ kg per second}$$

$$h = (200 - 192) + (215 - 200) + \text{depression head}$$

$$= 8 + 15 + 5 = 28 \text{ m}$$

$$h_f = \frac{flQ^2}{12.1\, d^5}$$

$$= \frac{0.072 \times 200 \times (0.03)^2}{12.1 \times (0.15)^5} = 14.22 \text{ m.}$$

$$H = h + h_f$$

$$= 28 + 14.22 = 42.22 \text{ m}$$

$$E = 0.75.$$

$$\text{Hence,} \quad \text{B.H.P.} = \frac{WH}{75E}$$

$$= \frac{30 \times 42.22}{75 \times 0.75}$$

$$= 22.52.$$

Adopt 3 units of 10 B.H.P. each together with one stand-by unit of the same capacity.

QUESTIONS

1. Why is pumping of water required in water supply projects?
2. What considerations govern the choice of a particular type of pump?
3. Discuss in detail the utility of air lift pumps in water supply projects.

is observed. The difference between the total amount of soap solution and the lather factor indicates the hardness of water.

The water, having hardness of about 5 degrees, is reasonably soft water and a very soft water is tasteless. Hence, for potable water, the hardness should preferably be more than 5 degrees but less than 8 degrees or so.

For the purpose of convenience, a tentative scale of hardness may be framed as shown in table 5-1.

TABLE 5-1
SCALE OF HARDNESS

No.	Nature of water	Hardness in degrees
1	Extremely soft	1
2	Very soft	2
3	Soft	3
4	Moderately soft	6
5	Moderately hard	7
6	Hard	9
7	Very hard	11
8	Excessively hard	15
9	Too hard for use	17

The hardness is normally expressed in terms of calcium carbonate. Now the chemical analyses for individual ions are usually given in terms of that ion. It will thus be necessary to convert the analytical results to the common denominator.

$$\text{Hardness in mg/l as } CaCO_3 = M^{++}\ (\text{mg/l}) \times \frac{\text{equivalent wt. of } CaCO_3}{\text{equivalent wt. of } M^{++}}$$

where M represents any ion or radical.

Now, $$\text{Equivalent weight} = \frac{\text{Molecular weight}}{X}$$

where

X = for acids, the number of moles of H^{++} obtainable from 1 mole of acid

X = for bases, the number of moles of H^{++} with which 1 mole of base will react.

Thus, $$\text{Equivalent weight of } CaCO_3 = \frac{(40 + 12 + 3 \times 16)}{2} = 50.$$

For solving problems on hardness, the following facts should be noted:

(1) The alkalinity will be caused by positively charged Ca^{++}, Mg^{++} and Sr^{++} ions and negatively charged CO_3^{--}, and HCO_3^{-} ions only. The readings of other metals should be ignored.

(2) The equivalent weights of Ca^{++}, Mg^{++} and Sr^{++} will be respectively as follows:

$$Ca = 40/2 = 20;$$
$$Mg = 24.4/2 = 12.2; \text{ and}$$
$$Sr = 87.6/2 = 43.8.$$

(3) For measuring alkalinity, the reading of only CO_3^{--} or HCO_3^{-} will be required and expressed as percentage, they can be found out from the following relations:

$$\left.\begin{array}{l}\text{Total alkalinity}\\ \text{as } HCO_3 \text{ in mg/l}\end{array}\right\} = \left\{\begin{array}{c}\text{Bicarbonate alkalinity}\\ \text{in mg/l}\end{array}\right\} \times 1.22$$

$$\left.\begin{array}{l}\text{Total alkalinity}\\ \text{as } CO_3 \text{ in mg/l}\end{array}\right\} = \left\{\begin{array}{c}\text{Carbonate alkalinity}\\ \text{in mg/l}\end{array}\right\} \times 0.60$$

$$\left[\begin{array}{lll}\text{Molecular wt of } HCO_3 & = (1 + 12 + 3 \times 16) & = 61\\ \text{Molecular wt of } CO_3 & = (12 + 3 \times 16) & = 60\end{array}\right]$$

Problem 5-1.

The analysis of water from a bore shows the following results in mg/l:

Ca = 60, Mg = 48, Na = 103.5, K = 19.5
HCO_3 = 244, SO_4 = 220.8, Cl = 78.1.

Find out the total hardness, carbonate hardness and non-carbonate hardness.

Solution:

$$\text{Total hardness} = (60 \times 50/20 + 48 \times 50/12.2)$$
$$= (150 + 196.72) = 346.72 \text{ mg/l as } CaCO_3.$$

$$\left.\begin{array}{l}\text{Total alkalinity}\\ \text{as } HCO_3 \text{ in mg/l}\end{array}\right\} = \left\{\begin{array}{c}\text{Bicarbonate alkalinity}\\ \text{in mg/l}\end{array}\right\} \times 1.22$$

$$\therefore \quad 244 = \text{Bicarbonate alkalinity} \times 1.22$$

$$\therefore \text{Bicarbonate alkalinity} = 244/1.22 = 200 \text{ mg/l.}$$

In this case,

$$\text{Alkalinity} < \text{T.H.}$$

$$\therefore \quad \text{C.H.} = \text{Alkalinity} = 200 \text{ mg/l.}$$

Then, $$\text{N.C.H.} = \text{T.H.} - \text{C.H.}$$
$$= (346.72 - 200) = 146.72 \text{ mg/l.}$$

Problem 5.2.

The analysis of a sample of water shows the following results in mg/l:

$Na = 20$ $Cl = 40$
$K = 30$ $HCO_3 = 67$
$Ca = 5$ $SO_4 = 5$
$Mg = 10$ $NO_3 = 10$

The concentration of stroncium (Sr) is equivalent to a hardness of 2.29 mg/l and the carbonate alkalinity in this water is zero. Calculate the total hardness, carbonate hardness and non-carbonate hardness in mg/l as $CaCO_3$.

Solution:

$$\text{Total hardness} = \frac{Ca^{++} \times 50}{20} + \frac{Mg^{++} \times 50}{12.2} + 2.29$$
$$= \frac{5 \times 50}{20} + \frac{10 \times 50}{12.2} + 2.29$$
$$= (12.5 + 40.98 + 2.29)$$
$$= 55.77 \text{ mg/l as } CaCO_3.$$

Bicarbonate alkalinity $= 67/1.22 = 54.92$ mg/l as $CaCO_3$.

In this case,

Alkalinity < T.H.

$\therefore$ C.H. = Alkalinity = 54.92 mg/l as $CaCO_3$.

Then, N.C.H. = T.H. − C.H.

$= (55.77 - 54.92) = 0.85$ mg/l as $CaCO_3$.

Problem 5.3.

The results obtained from a sample of water are as follows in mg/l:

$Na = 20$ $Sr = 2$
$K = 30$ $Cl = 40$
$Ca = 6$ $HCO_3 = 72$
$Mg = 11$ $SO_4 = 5$

Find out T.H., C.H. and N.C.H. in mg/l as $CaCO_3$.

Solution:

$$\text{Total hardness} = (6 \times 50)/20 + (11 \times 50)/12.2 + (2 \times 50)/43.8$$
$$= (15 + 45.08 + 2.28)$$
$$= 62.36 \text{ mg/l as } CaCO_3.$$

Bicarbonate alkalinity $= 72/1.22 = 59.02$ mg/l as $CaCO_3$.

In this case,

Alkalinity < T.H.

$\therefore$ C.H. = Alkalinity = 59.02 mg/l as $CaCO_3$.

Then, N.C.H. = T.H. − C.H. = (62.36 − 59.02)

= 3.34 mg/l as $CaCO_3$.

Problem 5.4.

The total hardness value obtained from the complete analysis of a water sample is found to be 116 mg/l. The analysis further shows that the concentrations of all the *three* principal cations causing hardness are numerically the same. If the value of C.H. is 58 mg/l, calculate the following:

(1) the value of N.C.H.;
(2) the concentrations of principal cations; and
(3) the value of total alkalinity in mg/l.

Solution:

T.H. = C.H. + N.C.H.

In the given problem,

T.H. = 116 mg/l and C.H. = 58 mg/l.

$\therefore$ 116 = 58 + N.C.H.

$\therefore$ N.C.H. = (116 − 58) = 58 mg/l as $CaCO_3$.

Let P = Concentration of principal cations.

Then, T.H. $= (P \times 50)/20 + (P \times 50)/12.2 + (P \times 50)/43.8$

$\therefore$ 116 = P (2.5 + 4.1 + 1.14)

$\therefore$ P = 116/7.74 = 14.99, say 15 mg/l

$\therefore$ Concentrations of Ca^{++}, Mg^{++} and Sr^{++} are 15 mg/l.

In this case,

Alkalinity < T.H.

$\therefore$ Total alkalinity = C.H. = 58 mg/l as $CaCO_3$.

(4) *Hydrogen-ion concentration (pH value)*: The acidity or alkalinity of water is measured in terms of its pH value or H-ion concentration.

The pure water (H_2O) consists of positively charged hydrogen or H-ions combined with negatively charged hydroxyl or OH-ions. But the process of dissociation takes place in pure water and hence it contains some uncombined positively charged H-ions and some for ready reference. This test is simple and hence it is commonly carried out in the public health laboratories. The usual indicators are Benzol yellow, Methyl red, Bromphenol blue, etc. for acidic range and Thymol blue, Phenol red, Tolyl red, etc. for alkaline range.

Problem 5-5.

In a water treatment plant, the pH values of entering and leaving waters are respectively 7.5 and 8.5. Assuming linear variation of pH with time, find out the average pH value of water.

Solution:

By definition,

$$pH = -\log_{10}H$$

For entering water,

$$pH = 7.5$$

$$\therefore \quad 7.5 = -\log_{10}H$$

$$\therefore \quad H = 10^{-7.5}$$

For leaving water,

$$pH = 8.5$$

$$\therefore \quad 8.5 = -\log_{10}H$$

$$\therefore \quad H = 10^{-8.5}$$

$$\therefore \quad \text{Average value of } H = \frac{10^{-7.5} + 10^{-8.5}}{2}$$

$$= 10^{-8.5}\left[\frac{10 + 1}{2}\right] = 5.50 \times 10^{-8.5}$$

$$\therefore \text{ Average pH value of water} = -\log_{10}H$$

$$= -\log_{10}(5.50 \times 10^{-8.5})$$

$$= (8.50 - 0.7404) = 7.7596.$$

Problem 5-6.

Calculate pH and OH values of freshly prepared distilled water.

Solution:

As per equation (3),

$$[H^+] \times [OH^-] = 10^{-14} \text{ mole/l}$$

In freshly distilled water, the concentrations of both the ions will be the same say, C moles/litre.

hen,

$$C \times C = 10^{-14}$$

$$C = 10^{-7}$$

$$[H^+] = 10^{-7} \text{ and } [OH^-] = 10^{-7}$$

ow,

$$pH = -\log_{10}[H^+]$$

$$= -\log_{10}[10^{-7}] = -[-7] = 7$$

Similarly

$$pOH = 7.$$

roblem 5-7.

A factory discharges 50 m^3/day of waste having pH = 11. If e waste contains KOH only, find out the quantity of KOH in kg/day.

olution:

$$pH + pOH = 14$$

$$11 + pOH = 14$$

$$pOH = 14 - 11 = 3.$$

Thus the concentration of hydoxycl ion in the given water is 10^{-3} oles/litre i.e. $[OH^-] = 10^{-3}$ moles/litre.

The molecular weight of KOH in 1 litre solution works out to

$$(39 + 16 + 1) = 56 \text{ g.}$$

$$\text{KOH in g/litre} = 56 \times 10^{-3}$$

$$\text{KOH in kg/litre} = 56 \times 10^{-6}$$

ow, $\text{Discharge} = Q = 50 \text{ m}^3\text{/day} = 50 \times 10^3 \text{ litres/day.}$

uantity of KOH in given waste $= (56 \times 10^{-6} \times 50 \times 10^3)$ kg/day

$$= 2.80 \text{ kg/day.}$$

roblem 5-8.

Calculate the pH of 1000 mg/l of $Ca(OH)_2$.

olution:

The molecular weight of $Ca(OH)_2$ works out to $[40 + 2\,(16+1)]$

$$= 74 \text{ g/l.}$$

Now, 74 g/litre contains 2 moles of $[OH^-]$.

1 g/litre contains $\frac{2}{74}$ moles of $[OH^-]$

Thus, $[OH^-] = \frac{2}{74}$

∴ $pOH = -\log_{10}[OH^-]$

$= -\log_{10}[2/74]$

$= -\log_{10}[0.027] = 1.5686.$

Now, $pH + pOH = 14$

∴ $pH = 14 - pOH = (14 - 1.5686)$

$= 12.4314$

∴ pH of 1000 mg/l i.e. 1 g/l of $Ca(OH)_2$ = 12.4314.

Problem 5-9.

Find out the pH of the following mixture:

	Volume	pH
Solution A ..	500 ml	6
Solution B ..	500 ml	5

Solution:

As the volume of both the solutions in the mixture i.e. A and B is the same, the morality of the mixture will be half in 1000 ml.

pH of A = 6 i.e. $[H^+]$ of A $= 10^{-6}$ mole/litre

pH of B = 5 i.e. $[H^+]$ of B $= 10^{-6}$ mole/litre

$$\text{pH of new mixture} = \left(\frac{1}{2} \times 10^{-6}\right) + \left(\frac{1}{2} \times 10^{-5}\right)$$

$$= (0.5 \times 10^{-6}) + (5 \times 10^{-6})$$

$$= 5.5 \times 10^{-6} \text{ mole/litre}$$

∴ $$\text{pH of new mixture} = -\log_{10}[H^+]$$

$$= -\log_{10}(5.5 \times 10^{-6})$$

$$= (-0.7404 + 6)$$

$$= 5.2596.$$

Problem 5-10.

Find out the pH of the mixture which will be formed by mixing the following *two* volumes:

	Volume	pH
Solution A ..	100 ml	6
Solution B ..	900 ml	5

Solution:

In this case, the volumes of A and B are not the same in 1000 ml mixture.

pH of A = 6 i.e. $[H^+]$ of A $= 10^{-6}$ mole/litre

pH of B = 5 i.e. $[H^+]$ of B $= 10^{-5}$ mole/litre

For solution A:

The volume of solution A is 100 ml and concentration of $[H^+]$ is 10^{-6} mole/litre i.e. 10^{-6} moles per 1000 ml.

∴ Concentration of $[H^+]$ in 100 ml $= 10^{-6} \times \frac{100}{1000}$

∴ $[H^+]_A = 10^{-7}$ mole/litre.

For solution B:

The volume of solution B is 900 ml and concentration of $[H^+]$ is 10^{-5} mole/litre i.e. 10^{-5} moles per 1000 ml.

∴ Concentration of $[H^+]$ in 900 ml $= 10^{-5} \times \frac{900}{1000}$

∴ $[H^+]_B = 9 \times 10^{-6}$ mole/litre.

Concentration of $[H^+]$ in mixture $= [H^+]_A + [H^+]_B$

$$= [10^{-7}] + [9 \times 10^{-6}]$$

$$= (0.1 \times 10^{-6}) + (9 \times 10^{-6})$$

$$= 9.1 \times 10^{-6} \text{ mole/litre}$$

∴ $$pH = -\log_{10}(9.1 \times 10^{-6})$$

$$= (-0.959 + 6) = 5.041.$$

Problem 5-11.

There are *three* samples *X*, *Y* and *Z* of water having pH values of 4.5, 5.5 and 6.5 respectively. Calculate how many times *X* is acidic than *Z*

Solution:

$$pH = -\log_{10}[H^+]$$

Sample *X*:

$$pH = 4.5$$

∴ $$4.5 = -\log_{10}[H^+]$$

∴ $$[H^+] = 10^{-4.5} \text{ mole/litre.}$$

Sample Z:

$$pH = 6.5$$

$$6.5 = -\log_{10}[H^+]$$

$$\therefore \quad [H^+] = 10^{-6.5} \text{ mole/litre.}$$

$$\therefore$$

$$\therefore \quad \frac{\text{Concentration of } [H^+] \text{ ion in } X}{\text{Concentration of } [H^+] \text{ ion in } Z} = \frac{10^{-4.5}}{10^{-6.5}} = 100$$

Thus sample X is 100 times acidic than sample Z.

Problem 5-12.

What would be the pH of a solution containing 1.70×10^{-8} g of hydroxide per litre? Assume molecular weight of OH as 17 g.

Solution:

$$[OH^-] = \frac{17 \times 10^{-9}}{17} = 10^{-9} \text{ mole/l}$$

$$\therefore \quad pOH = -\log(10^{-9}) = 9$$

$$\text{Now, } pH + pOH = 14$$

$$\therefore \quad pH = (14 - 9) = 5.$$

Problem 5-13.

If the hydrogen concentration is 3×10^{-2} mole/l, calculate the hydroxide concentration.

Solution:

As per equation (3),

$$[H^+] \times [OH^-] = 10^{-14} \text{ mole/l}$$

$$\therefore \quad [3 \times 10^{-2}] \times [OH^-] = 10^{-14} \text{ mole/l}$$

$$\therefore \quad [OH^-] = \frac{1}{3} \times 10^{-12} \text{ mole/l}$$

(5) ***Alkalinity:*** The term *alkalinity* with reference to the water and waste water is defined as the capacity of substances contained in the water to take up hydroxium (H_3^+O) to reach a defined pH value (4.3 to 14). The alkalinity is due to the presence of bicarbonate (HCO_3^-), carbonate (CO_3^{--}) or hydroxide (OH^-).

The determination of alkalinity is very useful in waters and wastes because it provides buffering to resist the changes in pH value. The alkalinity is usually divided into the following *two* parts:

(1) Total alkalinity i.e. above pH 4.5

(2) Caustic alkalinity i.e. above pH 8.2.

The alkalinity is measured by the volumetric analysis. The various types of indicators are available for this purpose. The commonly adopted *two* indicators are as follows:

(1) Phenolphthalein : pink above pH 8.2 and colourless below pH 8.2

(2) Methyl orange : red below pH 4.5 and yellow-orange above pH 4.5.

The bromcresol green-methyl red indicator may be preferable to methyl orange as the colour change from greenish-blue above pH 4.5 to light pink below pH 4.5 is more definite.

The amount of alkalinity is expressed in terms of $CaCO_3$. If the strength of titrant solution is N/50, 1 ml of titrant solution will be equal to 1 mg $CaCO_3$ because the equivalent weight of $CaCO_3$ is 50.

$$\text{Thus, Alkalinity in mg/l as } CaCO_3 = \frac{\text{Total reading}}{\text{Vol. of sample in ml}} \times 1000.$$

If the strength of titrant solution is N/40, the equation will be as follows:

$$\text{Alkalinity in mg/l as } CaCO_3 = \frac{\text{Total reading} \times (0.025 \times 50 \times 1000)}{\text{Vol. of sample in ml}}$$

$$= \frac{\text{Total reading}}{\text{Vol. of sample in ml}} \times 1250.$$

The neutralization of OH^- is complete at pH 8.2. The neutralization of CO_3^{--} is only half complete at pH 8.2 and not fully completed until a pH value of 4.5 is reached. Thus alkalinity on pH scale is represented as follows:

(1) The range of total alkalinity is 4.5 to 14.

(2) The range of bicarbonate i.e. HCO_3^- alkalinity is from 4.5 to 8.2.

(3) The range of carbonate i.e. CO_3^{--} alkalinity is from 8.2 to 10.

(4) The range 0 to 4.5 indicates no alkalinity.

Table 5-2 can be used for finding out the alkalinity of a sample with the process of titration. The letter P indicates phenolphthalein reading and the letter T indicates total alkalinity.

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TABLE 5-2
DETERMINATION OF ALKALINITY

Result of titration	Hydoxide alkalinity as $CaCO_3$ (OH^-)	Carbonate alkalinity as $CaCO_3$ (CO_3^{--})	Bicarbonate alkalinity as $CaCO_3$ (HCO_3^-)
P = 0	0	0	T
P < 0.5 T	0	2P	T − 2P
P = 0.5 T	0	2P	0
P > 0.5 T	2P − T	2(T − P)	0
P = T	T	0	0

Following rules should be kept in mind while finding out the alkalinity of a sample:

(1) For simplicity, it is assumed that HCO_3^- and OH^- alkalies cannot come together in the same sample.

(2) The alkalinities of other than carbonate, bicarbonate and hydroxide origin are absent.

(3) OH^- alone gives initial pH of about 10.

(4) CO_3^{--} will be present at $pH \geq 8.2$

(5) OH^- and CO_3^{--} together give initial pH of about 10.

(6) CO_3^{--} and HCO_3^- can exist together.

(7) HCO_3^- alone gives initial $pH < 8.2$.

The determination of alkalinity of water is helpful for the following *reasons*:

(i) It assists in finding out the quantity of lime and soda-ash required for the removal of hardness.

(ii) It helps to neutralise the acids produced during flocculation.

(iii) It leads to the reactions which may occur between alkalinity and certain cations in the water. The resultant precipitate can foul pipes and other appurtenances of the water distribution systems.

(iv) The excess alkalinity is harmful for irrigation which leads to the soil damage and reduce crop yields.

(v) The highly alkaline water is usually unpalatable.

(vi) The large amount of alkalinity imparts a bitter taste to the water.

(vii) The natural waters are sometimes rendered alkaline to control corrosion due to acids.

(viii) The waste waters containing excess caustic alkalinity are not to be discharged into natural streams or sewers.

(ix) The water having alkalinity less than 250 mg/1 is desirable for domestic consumption and for R.C.C. construction.

blem 5-14.

From the following data of volumetric analysis, calculate the roxide, carbonate and bicarbonate alkalinities:

Sample 100 ml	Total ml of titrant to reach end point	
	Phenolphthalein	Mythyl orange
A	10	15.5
B	14.4	38.6
C	8.2	8.4
D	0	12.7

lution:

mple A:

$$P = \frac{10 \times 1000}{100} = 100$$

$$T = \frac{15.5 \times 1000}{100} = 155$$

$$0.5\ T = 77.5$$

As P > 0.5 T, from table 5-2,

$$OH^- \text{ alkalinity } = 2P - T = (200 - 155) = 45$$

$$CO_3^{--} \text{ alkalinity } = 2(T - P) = 2(155 - 100) = 110$$

$$HCO_3^- \text{ alkalinity } = 0.$$

mple B:

$$P = \frac{14.4 \times 1000}{100} = 144$$

$$T = \frac{38.6 \times 1000}{100} = 386$$

$$0.5\ T = 193$$

As P < 0.5 T, from table 5-2,

$$OH^- \text{ alkalinity } = 0$$

$$CO_3^{--} \text{ alkalinity } = 2P = 288$$

$$HCO_3^- \text{ alkalinity } = T - 2P = (386 - 288) = 98.$$

Sample C:

$$P = \frac{8.2 \times 1000}{100} = 82$$

$$T = \frac{8.4 \times 1000}{100} = 84$$

$$0.5\,T = 42$$

∴ As $P > 0.5\,T$, from table 5-2,

OH^- alkalinity $= 2P - T = (164 - 84) = 80$

CO_3^{--} alkalinity $= 2(T - P) = 2(84 - 82) = 4$

HCO_3^- alkalinity $= 0$.

Sample D:

$$P = 0$$

$$T = \frac{12.7 \times 1000}{100} = 127$$

As $P = 0$, from table 5-2,

OH^- alkalinity $= 0$

CO_3^{--} alkalinity $= 0$

HCO_3^- alkalinity $= T = 127$.

Problem 5-15.

Find out the total and individual (species-wise) alkalinity from the following laboratory record:

Strength of titrant : N/40 → মানে N = 50 L

Volume of sample : 50 ml ↘ $= 50 \times 10^3$ mL

Phenolphthalein end point : 5.6 ml

Methyl orange end point : 13.5 ml. ✓

Also estimate the pH value of sample. $\frac{50 \times 1000}{40}$ (N) ←

Solution:

As strength of titrant is N/40,

$$P = \frac{5.6 \times 1250}{50} = 140$$

$$T = \frac{5.6 \times 1250}{50} = 337.5$$

$$0.5\,T = 168.75$$

∴ As $P < 0.5\,T$, from table 5-2,

OH^- alkalinity $= 0$

CO_3^{--} alkalinity $= 2P = 280$

HCO_3^- alkalinity $= T - 2P = (337.5 - 280) = 57.5$.

As CO_3^{--} and HCO_3^- exist together, the pH value of sample will be between 8.2 to 10.

Problem 5-16.

A water sample with pH 9 had a caustic alkalinity of 70 mg/l, total alkalinity of 230 mg/l and total hardness of 300 mg/l, all as $CaCO_3$. Calculate the amounts of the various forms of alkalinity present and the amount of non-carbonate hardness.

Solution:

The pH of sample is 9 and hence the neutralization of CO_3^{--} is only half completed.

∴ Carbonate i.e. CO_3^{--} alkalinity $= 2 \times$ Caustic alkalinity

$= (2 \times 70)$

$= 140$ mg/l.

Now, Total alkalinity $= CO_3^{--}$ alkalinity $+ HCO_3^-$ alkalinity

∴ $230 = 140 + HCO_3^-$ alkalinity

∴ HCO_3^- alkalinity $= (230 - 140) = 90$ mg/l.

Also, Total hardness = Alkalinity + Non-carbonate hardness

∴ N.C.H. $= (300 - 230)$

$= 70$ mg/l.

---

(6) *Acidity:* The term *acidity* with reference to the water and waste water is defined as the capacity of substances contained in the water to take up hydroxyl ions (OH^-) to reach a defined pH value (0 to 8.2).

The acidity are of the following *two* types:

(i) Carbon dioxide acidity

(ii) Mineral acidity.

Now, out of *three* forces which oppose the tendency of settlement of particle, the attempts are made to control the first and second forces in purification process of water. The third force, namely, the viscosity of water is unpracticable to control as it is dependent on temperature. The control of temperature of a huge quantity of water becomes unreasonable and uneconomical.

The velocity of flow can be decreased by increasing the length of travel and thus a particle is allowed to stay for a longer period in the sedimentation tank. The particle is thus given maximum opportunity to come down and settle at the bottom of tank.

The size and shape of the particle are altered by the addition of certain chemicals in water. These chemicals are known as the *coagulants* and their action of making sedimentation tanks effective will be discussed at length in the next chapter.

Problem 6-1.

Find out the velocity of settlement of spherical discrete particles of 0.08 mm diameter with specific gravity 2.67 in water at 20°C.

Solution:

As per Stokes's law,

$$v = 418\,(s - s_1)\,d^2\,\frac{3T + 70}{100}$$

where d = diameter of discrete particles = 0.08 mm

T = 20°C

s = specific gravity of the particle = 2.67

s_1 = specific gravity of water = 1.00

v = velocity of settlement in mm per second.

Substituting

$$v = 418\,(2.67 - 1.00)\,(0.08)^2\,\frac{(3 \times 20) + 70}{100}$$

$$= 5.808 \text{ mm per second.}$$

Problem 6-2. **

✓ **A settling tank is designed to remove spherical particles of 0.80 mm diameter with specific gravity 1.20 from the water at 22°C. Determine the removal of spherical discrete particles of 0.40 mm diameter with specific gravity 1.20 by this tank. Assume ideal settling conditions.**

Solution:

As per Stokes's law,

$$v = 418\,(s - s_1)\,d^2\,\frac{3T + 70}{100}$$

For 0.80 mm diameter particles,

$$v_1 = 418\,(1.20 - 1.00)\,(0.80)^2\,\frac{(3 \times 22 + 70)}{100}$$

$$= 113.70\,(0.80)^2 \text{ mm per second.}$$

For 0.40 mm diameter particles,

$$v_2 = 418\,(1.20 - 1.00)\,(0.40)^2\,\frac{(3 \times 22 + 70)}{100}$$

$$= 113.70\,(0.40)^2$$

$$\therefore \frac{v_1}{v_2} = \frac{(0.80)^2}{(0.40)^2} = 4.00 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The settling tank is designed to remove 0.80 mm dia. discrete particles and if the same tank is used to remove 0.40 mm dia. discrete particles, the removal of latter will be proportional to the ratio of velocities of settlement. From equation (1),

$$\frac{v_2}{v_1} = \frac{1}{4}$$

$$= 25\% = \text{percentage removal of 0.40 mm diameter discrete particles.}$$

Types of sedimentation tanks:

Depending upon the nature of working, the sedimentation tanks are of the following *two* types:

I. Fill and draw type tanks

II. Continuous flow type tanks.

Each of the above type of sedimentation tank will now be briefly described.

I. Fill and draw type tanks:

Working: These are also known as the *quiescent type or intermittent type* sedimentation tanks. The working of tank is simple. The water is filled in the tank and it is then allowed to rest for a certain time. During the period of rest, the particles in suspension will settle down at the bottom of tank. The clear water is then drawn off and the tank is cleaned of silt and filled again.

period is found to vary from 4 to 8 hours and when coagulants are used, it may vary from 3 to 4 hours.

In this method, the depth of settling tank is to be taken into consideration. The depths usually provided for settling tanks vary from 3.50 to 6.00 metres.

(ii) *Overflow rate:* In this method, it is assumed that the settlement of a particle at the bottom of tank does not depend on the depth of tank. But it depends on the surface area of the tank. This assumption can be theoretically justified as follows:

Let L = Length of tank
B = Breadth of tank
D = Depth of tank = Side water depth = S.W.D.
C = Capacity of tank
T = Detention period
Q = Discharge or rate of flow
V = Velocity of descend of a particle to the bottom of tank = Surface overflow rate = S.O.R.

Then,
$$T = \frac{C}{Q} = \frac{L \times B \times D}{Q} \quad \ldots\ldots (1)$$

Also,
$$T = \frac{\text{Distance of descend}}{\text{Velocity of descend}}$$
$$= \frac{D}{V} = \frac{\text{S.W.D.}}{\text{S.O.R.}} \quad \ldots\ldots (2)$$

Equating (1) and (2),
$$\frac{L \times B \times D}{Q} = \frac{D}{V}$$

or
$$\text{S.O.R} = V = \frac{Q}{L \times B} \quad \ldots\ldots (3)$$

The equation (3) shows that the velocity of descend of a particle is independent of the depth of tank and it inversely varies as the surface area of the tank.

The quantity of water passing per hour per unit area of settling tank is known as the *surface overflow rate* and the design of settling tank is made on the basis of overflow rate. The depth of tank is assumed as about 180 cm to 360 cm. For plain rectangular sedimentation tanks, the overflow rate is about 500 to 750 litres per hour per m^2 and when coagulants are used, it is about 1000 to 1250 litres per hour per m^2.

Problem 6-3.

The overflow rate of a flocculator clarifier is 60 l/m^2-min. Express this rate in m^3/m^2-d. If S.W.D. is 3.50 m, calculate the detention period.

Solution:

$$\text{S.O.R.} = 60 \text{ l/m}^2\text{-min}$$
$$= 60 \times 10^{-3} \text{ m}^3/\text{m}^2\text{-min}$$
$$= 60 \times 10^{-3} \times 60 \times 24 \text{ m}^3/\text{m}^2\text{-d}$$
$$= 86.40 \text{ m}^3/\text{m}^2\text{-d.}$$

$$\text{Detention period} = T = \frac{\text{S.W.D.}}{\text{S.O.R.}} = \frac{3.50}{86.40}$$
$$= 0.04 \text{ day} = 0.96 \text{ hour.}$$

Problem 6-4.

Calculate the diameter and S.W.D. of a settling tank to treat a flow of 20 × 10^6 ml/d. The maximum S.O.R. is 18 m^3/m^2–d and detention period is 3 hours.

Solution:

$$Q = 20 \times 10^6 \text{ ml/d}$$
$$= \frac{20 \times 10^6}{1000} \text{ m}^3/\text{d}$$
$$= 20000 \text{ m}^3/\text{d.}$$

$$\text{Detention period} = T = \frac{\text{S.W.D.}}{\text{S.O.R.}}$$

$$\therefore \quad \text{S.W.D.} = \frac{3}{24} \times 18 = 2.25 \text{ m.}$$

$$\text{Surface area of settling tank} = \frac{\text{Discharge}}{\text{S.O.R.}} = \frac{20000}{18}$$

$$\therefore \quad \frac{\pi}{4} (\text{Diameter})^2 = 1111.11 \text{ m}^2$$

$$\therefore \quad \text{Diameter of settling tank} = 37.61, \text{ say } 38 \text{ m.}$$

Problem 6-5.

Calculate the dimensions of a rectangular plain sedimentation tank to treat 12 x 10^6 ml/day. Assume a detention period of 6 hours and the velocity of flow as 20 cm per second.

Solution:

$$Q = \text{Discharge or rate of flow}$$

$$= \frac{12 \times 10^6}{24} \times \frac{1}{1000} = 500 \text{ m}^3.$$

Now, Velocity of flow = 20 cm/minute = 0.20 m/minute

Length of tank required = Velocity of flow × Detention period

$$= 0.20 \times (6 \times 60) = 72 \text{ m}.$$

Also,

$$T = \frac{L \times B \times D}{Q}$$

$$\therefore \quad 6 = \frac{72 \times B \times D}{500}$$

$$\therefore \quad B \times D = \text{Cross-sectional area of tank}$$

$$= \frac{500 \times 6}{72} = 41.67 \text{ m}^2.$$

Assuming the effective depth of tank as 4 m and total depth with freeboard of 0.50 m as 4.50 m,

$$\text{Width of tank required} = \frac{41.67}{4} = 10.42 \text{ m, say } 10.50 \text{ m.}$$

Provide the sedimentation tank of dimensions 72 m × 10.50 m × 4.50 m.

Problem 6-6.

A rectangular tank with length of 15 m, width of 6 m and depth 3 m is to treat 2.40 × 10^6 ml/d. Calculate:

(1) Detention period of tank

(2) Average flow velocity through tank

(3) S.O.R.

Solution:

(1) *Detention period of tank:*

$$Q = 2.40 \times 10^6 \text{ ml/d}$$

$$= \frac{2.40 \times 10^6}{24} \text{ ml/hour}$$

$$= 100 \times 10^3 \text{ litres per hour} = 100 \text{ m}^3\text{/hour.}$$

Then,

$$T = \frac{L \times B \times D}{Q}$$

$$= \frac{15 \times 6 \times 3}{100}$$

$$= 2.70 \text{ hours.}$$

(2) *Average flow velocity through tank:*

$$\text{Flow velocity} = \frac{\text{Discharge}}{\text{Cross-sectional area}} = \frac{100}{6 \times 3} \times \frac{100}{60} \text{ cm/minute}$$

$$= 9.26 \text{ cm/minute.}$$

(3) *S.O.R.:*

$$\text{S.O.R.} = \frac{Q}{L \times B} = \frac{100}{15 \times 6} \times 1000$$

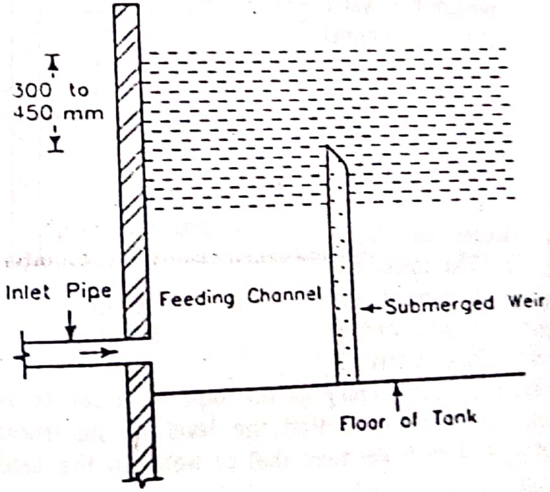
$$= 1111 \text{ litres per hour per m}^2.$$

---

(3) ***Inlet and outlet arrangements:*** The *inlet* is a device which is provided to distribute the water inside a tank and the *outlet* is a device which is meant to collect outgoing water. These arrangements should be properly designed and located in such a way that they do not form any obstruction or cause any disturbance to the flowing water.

If rate of inflow is equal to the rate of outflow, the water level of sedimentation tank is controlled. If *two* rates are different, the eddies or currents will be set up and they will greatly affect the working of tanks.

Some of the typical arrangements for inlets and outlets are shown in fig. 6-3 to fig. 6-6.



Inlet
Fig. 6-3

Fig. 6-3 shows a submerged inlet. It consists of a feeding channel which extends for the whole width of the tank and a submerged weir.

(6) ***Sodium aluminate:*** The chemical composition of this coagulant is $Na_2Al_2O_4$. This coagulant, when dissolved and mixed with water, reacts with salts of calcium and magnesium. Following are the chemical reactions:

$$Na_2Al_2O_4 + Ca(HCO_3)_2 = CaAl_2O_4 + Na_2CO_3 + CO_2 + H_2O \ldots\ldots (1)$$

$$Na_2Al_2O_4 + CaCl_2 = CaAl_2O_4 + 2NaCl \ldots\ldots (2)$$

$$Na_2Al_2O_4 + CaSO_4 = CaAl_2O_4 + Na_2SO_4 \ldots\ldots (3)$$

This coagulant removes carbonate or temporary hardness as seen from equation (1) and it also removes non-carbonate or permanent hardness as seen from equations (2) and (3). The effective range of pH value for this coagulant is 6 to 8.50 and as pH value of normal water lies within this range, the adjustment of pH value is not important when this coagulant is used. However this coagulant is costly and hence it cannot be adopted for treating water on a large scale. It may be adopted for treating water to be used for boilers or for water in which floc by aluminium sulphate is not easily formed.

Problem 7-1.

Find out the quantity of alum required to treat 9 million litres of water per day. The dosage of alum is 14 mg per litre. Also work out the amount of CO_2 released per litre of water treated.

Solution:

$$\text{Quantity of alum per day} = \frac{14 \times 9 \times 10^6}{10^6} = 126 \text{ kg.}$$

The chemical reaction is as follows:

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

$$\begin{aligned}\text{Now, Molecular wt. of alum} &= (2 \times 26.97) + (3 \times 32.066) \\ &\quad + (36 \times 1.008) + (30 \times 16) \\ &= (53.94 + 96.198 + 36.288 + 480) \\ &= 666.426, \text{ say } 666. \\ \text{Molecular wt. of } CO_2 &= (1 \times 12.01) + (2 \times 16) \\ &= 44.01, \text{ say } 44.\end{aligned}$$

Thus 666 mg of alum will release 6×44 mg of CO_2

$$\therefore \text{ 14 mg of alum will release} = \frac{14 \times 6 \times 44}{666} = 5.55 \text{ mg of } CO_2.$$

Problem 7-2. ⑮

A water treatment plant consumes ferrous sulphate and lime as coagulant at the rate of 10 mg of ferrous sulphate per litre of water. Find out the quantities of ferrous sulphate and lime required to treat 9 million litres of water.

Solution:

The chemical reactions involved are as follows:

$$FeSO_4 \cdot 7H_2O + Ca(OH)_2 = Fe(OH)_2 + CaSO_4 + 7H_2O$$

$$Ca(OH)_2 = CaO + H_2O.$$

$$\begin{aligned}\text{Now, Molecular wt. of } FeSO_4 \cdot 7H_2O &= (1 \times 55.85) + (1 \times 32.066) \\ &\quad + (11 \times 16) + (14 \times 1.008) \\ &= 278.028, \text{ say } 278. \\ \text{Molecular wt. of CaO} &= (40.08 + 16) \\ &= 56.08, \text{ say } 56.\end{aligned}$$

$$\text{Quantity of ferrous sulphate} = \frac{10 \times 9 \times 10^6}{10^6} = 90 \text{ kg.}$$

Also, 278 kg of ferrous sulphate will react with 56 kg of lime.

$$\therefore \left.\begin{array}{l}\text{Quantity of lime required} \\ \text{corresponding to 90 kg} \\ \text{of ferrous sulphate}\end{array}\right\} = \frac{50 \times 90}{278} = 18.13 \text{ kg.}$$

Feeding the coagulants:

The coagulants may be fed or allowed to enter water either in powder form or in solution form. The former is known as the *dry feeding* and the latter is known as the *wet feeding*. Each method of feeding will now be briefly described.

(1) ***Dry feeding:*** In dry feeding, the coagulant is stored in a powder form and it is then allowed to fall in the mixing channel in measured quantity. The dry feeding is desirable for various reasons as mentioned below:

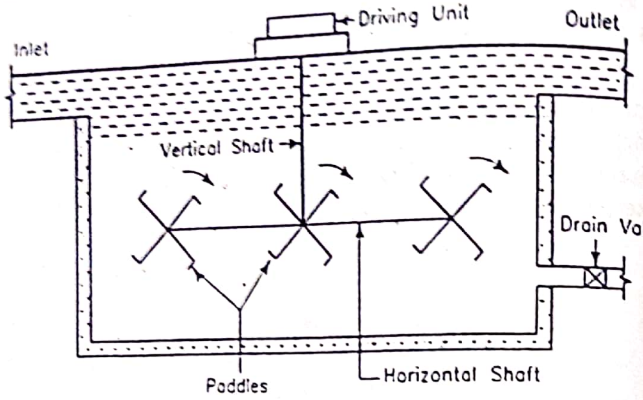
(1) It is simple in operation.

(2) It requires relatively less space for its working.

(3) It grants freedom from corrosion.

(4) It becomes possible to maintain neatness.

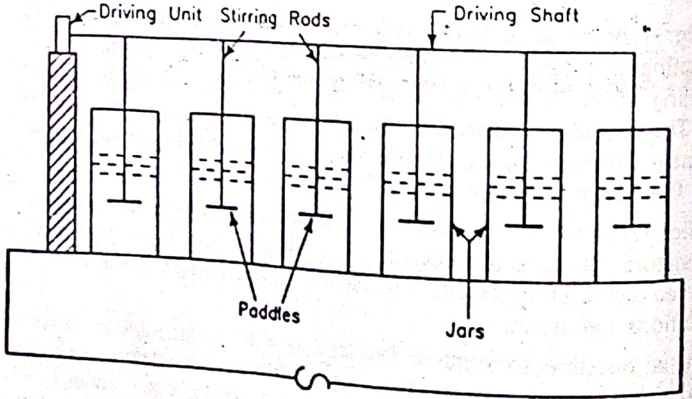
sedimentation tank. The detention period for floc chamber is about 15 to 40 minutes and that for tank, it is about 3 to 4 hours. The other details and aspects of design for such a tank are similar to those of a plain sedimentation tank. The cleaning of tanks is usually carried out at intervals of about 3 to 6 months.



Flocculator
FIG. 7-9

Jar test:

In order to determine approximately the dosage of coagulant, the usual test which is performed in the laboratory, is the *jar test.* The water for which dosage of coagulant is to be determined is placed in a number of jars or beakers having capacity of about 500 to 1000 millilitres.



Jar test
FIG. 7-10

Fig. 7-10 shows jar test with *six* jars. The various amounts of coagulant are then added in each jar. The driving unit is then started. The driving shaft rotates the paddles situated at lower ends of the stirring rods as shown in fig. 7-10. The paddles are rotated for 5 minutes at the speed of 30 to 40 R.P.M. and then slowly for about 20 minutes. The formation of floc in each jar is noted. The amount of coagulant in jar which produces good floc with the least amount of coagulant is preferred. The speed of paddles as well as time of mixing may be varied for different tests.

It is necessary to carry out this test frequently so as to determine optimum dose of coagulant and thus to achieve economy in its use. If the quality and characteristics of water are changing, the jar test should be done continuously.

Problem 7-3. ⑮

Design a coagulation sedimentation tank to treat 9 million litres of water per day. Make suitable assumptions where necessary.

Solution:

Average daily water to be treated $= \dfrac{9 \times 10^6}{10^3} = 9000 \text{ m}^3.$

Average hourly water to be treated $= \dfrac{9000}{24} = 375 \text{ m}^3.$

Assuming maximum hourly demand to be 1.50 times the average demand of water,

maximum hourly demand $= (375 \times 1.50) = 562.50 \text{ m}^3.$

Assume detention period of settling tank as 4 hours.

Then, $C = Q \times T$

where C = Capacity of settling tank in m^3

Q = Rate of flow per hour = 562.50 m^3 per hour

T = Detention period in hours = 4 hours.

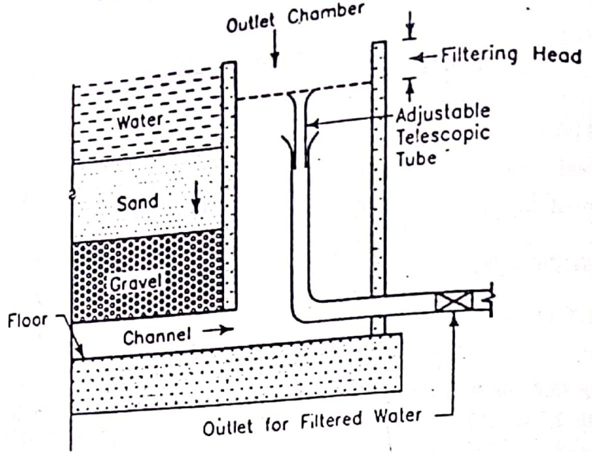
Substituting, $C = (562.50 \times 4) = 2250 \text{ m}^3.$

Assume effective depth of settling tank as 4 m.

Sectional area $= \dfrac{2250}{4} = 562.50 \text{ m}^2.$

Alternatively adopt overflow rate of 1000 litres per hour per m^2 of tank area.

Then, sectional area $= \dfrac{562.5 \times 10^3}{1000} = 562.50 \text{ m}^2.$



Cross-section through outlet chamber
FIG. 8-2

The depth of water on filter is to be carefully decided. It should neither be too small nor too high. Generally it is kept as equal to the height of filter media of sand.

The slow sand filters are usually worked for a maximum filtration head of 750 mm or so. But from the view point of safety, the maximum filtration head desired is obtained by multiplying the depth of filtering sand with a factor of 0.67 to 0.80. Thus, when specified limit of filtration head is reached, the filter requires cleaning.

For the purpose of cleaning, the top layer of sand is scraped or removed through a depth of about 15 mm to 25 mm. The water is then admitted to the filter. But the purified water is not taken into use until the formation of film around sand grains occurs. This may require a period of about *one* or *two* days.

When cleaning of filter had been done for a number of times, the effective depth of filter media of sand is reduced. In order to maintain the efficiency of filter, a fresh layer of about 150 mm depth of graded sand is then added to the filter. At places, where there is acute shortage of filtering sand, the scraped sand obtained during cleaning operations is washed and stored for future replacement.

The interval between *two* successive cleanings depends mainly on the nature of impurities present in water to be treated and the size of filtering sand. It usually varies from 1 to 3 months.

Rate of filtration: The rate of filtration for a normal slow sand filter varies from 100 to 200 litres per hour per m^2 of filter

Efficiency of slow sand filters: The efficiency of slow sand filters is as follows:

(1) *Bacterial load:* The slow sand filters are highly efficient in the removal of bacterial load from water. It is expected that they remove about 98 to 99 per cent of bacterial load from raw water and this percentage may be as high as 99.50 to 99.90 when pre-treatment has been given to the raw water. However, for complete removal of bacteria, the disinfection is essential.

(2) *Colour:* The slow sand filters are less efficient in the removal of colour of raw water. It is estimated that they remove about 20 to 25 per cent colour of raw water.

(3) *Turbidity:* The slow sand filters can remove turbidity to the extent of about 50 p.p.m. For water having greater turbidity than 60 p.p.m., it is necessary to give preliminary treatment and bring down its turbidity below 50 p.p.m.

Problem 8-1.

Find the area of slow sand filters required for a town having a population of 15000 with an average rate of demand as 160 litres per head per day.

Solution:

Maximum daily demand $= (15000 \times 160 \times 1.50)$

$= 3600000$ litres.

Assuming a rate of filtration as 150 litres per hour per m^2 of filter area,

$$\text{area of filter required} = \frac{3600000}{150 \times 24} = 1000 \text{ m}^2.$$

Let the size of one unit be 16.00 m × 12.50 m. Then provide 6 such units of slow sand filters including one unit as stand-by. The units may be arranged in series with 3 units on either side.

II. Rapid sand filters (gravity type):

Purpose: The great *disadvantage* of a slow sand filter is that it requires considerable space for its installation. This requirement makes it uneconomical for places where land values are high. As seen in problem 1, the area required for slow sand filter, only for a moderate town of 15000 population, works out to be 1000 m^2 and with future expansion, other additional equipment, etc., the area required for water supply project would be about 2000 m^2 or so.

and the working of filter is seriously disturbed. This phenomena is known as the *air binding* as air binds the filter and stops its working. The rate of filtration is consequently greatly reduced.

In case of rapid sand filters, the allowable loss of head is about 3 m to 3.50 m and the allowable negative head is about 1200 mm. The filter is to be washed when this limit of the allowable loss of head has been reached. It is usually cleaned after 2 to 3 days.

Troubles in operation: Following *two* troubles are generally encountered in operating rapid sand filters:

(1) Mud balls
(2) Cracking of filters.

(1) *Mud balls:* The mud balls are generally formed near the top of filter media. They may even be formed and distributed throughout the filter. The mud balls are caused due to insufficient washing of sand grains. The gelatinous film formed during filtration is not separated out from sand grains during washing. The mud balls interfere with the normal working of the filter and their size is about 25 mm to 50 mm.

(2) *Cracking of filters:* The fine material contained in the top layer of filter shrinks and this shrinkage tends to form cracks in the filter. These cracks are prominent near wall junctions.

To remove these troubles, the following *remedies* are adopted:

(1) The mud balls are broken with the help of rakers or some such equipment.
(2) The working of filter is carried out with high velocity of water.
(3) The damaged portion of filter media is replaced.

Rate of filtration: The chief *advantage* of a rapid sand filter is that its rate of filtration is very high. It is about 3000 to 6000 litres per hour per m^2 of filter area. The high rate of filtration results in considerable saving of space for the installation of filter.

Efficiency of rapid sand filters: The efficiency of rapid sand-filters is as follows:

(1) *Bacterial load:* The rapid sand filters are less effective in the removal of bacterial load. It is expected that they remove about 80 to 90 per cent of bacterial impurity present in water.

(2) *Colour:* The rapid sand filters are highly efficient in colour removal and the intensity of colour can be brought down below 10 on cobalt scale.

(3) *Turbidity:* The rapid sand filters can remove turbidity to the extent of 35 to 40 p.p.m. As water entering rapid sand filter is invariably given the treatment in coagulation sedimentation tank, it possesses less turbidity. This turbidity is easily brought down to the permissible limits by rapid sand filters.

Problem 8-2.

Find the area of rapid sand filters required for a town having a population of 80000 with an average rate of demand as 200 litres per head per day.

Solution:

$$\text{Maximum daily demand} = (80000 \times 200 \times 1.50) = 24000000 \text{ litres.}$$

Assuming a rate of filtration as 5000 litres per hour per m^2 of filter area,

$$\text{area of filter required} = \frac{24000000}{5000 \times 24} = 200 \text{ m}^2.$$

Let the size of one unit be 8 m x 5 m. Then provide 6 such units of rapid sand filters including one unit as standby. The units may be arranged in series with 3 units on either side.

Problem 8-3.

A rapid sand filter is required to treat a flow of 0.50 m^3 per second. The filtration rate is 120 m^3 per day per m^2 of filter area and it is provided that the filtration rate with one filter washing is not to exceed 150 m^3 per day per m^2 of filter area. Determine the number of units and the area of each unit to satisfy these conditions.

Each filter is washed for 5 minutes every 24 hours at a wash rate of 10 mm per second per m^2 of filter area. The filter remains out of operation for a total interval of 30 minutes per day. Calculate the percentage of filter output used for washing.

Solution:

$$\text{Maximum flow rate} = (0.5 \times 60 \times 60 \times 24) \text{ m}^3 \text{ per day}$$
$$= 43200 \text{ m}^3 \text{ per day.}$$

Note: The rate of filtration can also be expressed as m^3 per day per m^2 of filter area because of the relation 1 m^3 = 1000 litres.

Thus 120 m^3 per day per m^2 of filter area is equivalent to $\left(\frac{120 \times 1000}{24}\right)$

= 5000 litres per hour per m^2 of filter area.

$$\text{Filter area on the basis of maximum filtration rate} = \frac{43200}{150} = 288 \text{ m}^2.$$

$$\text{Filter area on the basis of minimum filtration rate} = \frac{43200}{120} = 360 \text{ m}^2.$$

$$\text{Area of one filter unit} = (360 - 288) = 72 \text{ m}^2.$$

$$\text{Total nos. of filters} = \frac{\text{Maximum filter area}}{\text{Area of one unit}} = \frac{360}{72} = 5.$$

Now, each unit of filter is working at the filtration rate of 120 m^3 per day per m^2 of filter area and the operation of filter is out of order for a period of 30 minutes.

Hence the total working period per day of each filter is

$$(24 - 0.5) = 23.5 \text{ hours.}$$

$$\text{Output of each unit per day} = \text{Area} \times \text{Filtration Rate} \times \frac{\text{Working period}}{24}$$

$$= \left(72 \times 120 \times \frac{23.5}{24}\right)$$

$$= 8460 \text{ m}^3.$$

$$\text{Wash rate} = 10 \text{ mm per second per m}^2 \text{ of filter area}$$

$$= (10 \times 10^{-3} \times 60) \text{ m per minute per m}^2 \text{ of filter area.}$$

$$\text{Washing period} = 5 \text{ minutes}$$

$$\therefore \text{Wash-water required per day} = \text{Area} \times \text{Wash rate} \times \text{Washing period}$$

$$= 72 \times (10 \times 10^{-3} \times 60) \times 5$$

$$= 216 \text{ m}^3.$$

$$\text{Percentage of filter output used for washing} = \frac{\text{Wash-water required}}{\text{Output of each unit}} \times 100$$

$$= \frac{216}{8460} \times 100$$

$$= 2.55\%.$$

Comparison between slow sand filters and rapid sand filters (gravity type):

We have so far discussed at length slow sand filters and rapid sand filters (gravity type) separately. In order to bring out the points of differences between similar items of slow sand filters and rapid sand filters, a chart as shown in table 8-1, is prepared.

TABLE 8-1

DIFFERENCE BETWEEN TWO TYPES OF FILTERS

No.	Item	Slow sand filters	Rapid sand filters (gravity type)
1	Base material of gravel	Varies from 3 to 65 mm in size and 300 to 750 mm in depth.	Varies from 3 to 40 mm in size and 600 to 900 mm in depth.
2	Coagulation	Not required.	Essential.
3	Compactness	Requires large area for its installation.	Requires small area for its installation.
4	Construction	Simple.	Complicated as underdrainage system is to be properly designed and constructed.
5	Cost of operation	Low.	High.
6	Depreciation of plant	Low.	High.
7	Economy	High initial cost of both, land and material.	Cheap and quite economical.
8	Efficiency	Very efficient in the removal of bacteria but less efficient in the removal of colour and turbidity.	Less efficient in the removal of bacteria but more efficient in the removal of colour and turbidity.
9	Filter media of sand	Effective size varies from 0.20 to 0.30 mm and uniformity coefficient is about 2 to 3.	Effective size varies from 0.35 to 0.60 mm and uniformity coefficient is about 1.2 to 1.7.
10	Flexibility	Not flexible for meeting variations in demand.	Quite flexible for reasonable fluctuations in demand.
11	Loss of head	150 mm to 750 mm.	3 m to 3.50 m.
12	Method of cleaning	Scraping of top layer of 15 mm to 25 mm thickness. Long and laborious method.	Agitation and back-washing with or without the help of compressed air. Short and speedy method.
13	Period of cleaning	1 to 3 months.	2 to 3 days.
14	Rate of filtration	100 to 200 litres per hour per m^2 of filter area.	3000 to 6000 liters per hour per m^2 of filter area.
15	Skilled supervision	Not essential.	Essential.
16	Suitability	The filter can be constructed of local labour and material. It is suitable for small towns and villages where land is cheaply available.	It is suitable for big cities where land cost is high and variation in demand of water is considerable.

(6) It should take only reasonable time in killing the harmful pathogenic organisms at normal temperature.)

It has been universally recognised that the chlorine is an ideal material for the disinfection for treating water on a large scale. The disinfection at present therefore is mainly carried out by chlorination. However, there are other minor methods of disinfection. We will discuss these methods before we take up the discussion on chlorination.

Theory of disinfection:

The rate of kill in general is expressed by the Chick's law as follows:

$$\frac{dN}{dt} = -KN_t \qquad \text{.......(1)}$$

where
K = Reaction rate constant for particular disinfectant
N = Number of viable organisms
N_t = Number of organisms at any time t.

Integrating equation (1),

$$\int \frac{dN}{dt} = -\int KN_t$$

$$\therefore \int \frac{dN}{N_t} = -\int K\,dt$$

$$\therefore \log_e N_t = -Kt + C \qquad \text{.......(2)}$$

At $t = 0$, $N_t = N_o$ = Number of organisms initially.

$$\therefore \log_e N_o = C.$$

∴ Equation (2) will be,

$$\log_e N_t = -Kt + \log_e N_o$$

$$\therefore \log_e \frac{N_t}{N_o} = -Kt$$

$$\therefore t = \frac{1}{K}\log_e \frac{N_o}{N_t}$$

Changing to base 10,

$$t = \frac{1}{K}\log_{10} \frac{N_o}{N_t}$$

Since N_t will never reach zero, it is the usual practice to specify kill as a percentage e.g. 99.7%.

The most popular disinfectant of water is chlorine and it does t obey the equation mentioned above. But it follows the relation ven by the expression:

$$\frac{dN}{dt} = -KN_t t$$

$$\int \frac{dN}{N_t} = \int -Kt\,dt$$

$$\log_e N_t = -\frac{Kt^2}{2} + C.$$

$$t = 0,\ N_t = N_o$$

$$C = \log_e N_o$$

$$\log_e \frac{N_t}{N_o} = -\frac{Kt^2}{2}$$

$$t^2 = \frac{2}{K}\log_{10}\frac{N_o}{N_t}$$

$$t = \sqrt{\frac{2}{K}\log_{10}\frac{N_o}{N_t}}$$

blem 9-1.

To obtain 99.70% kill of bacteria, the ozone is to be used in ater with a residual of 0.6 mg/l. The reaction constant under these onditions is 3×10^{-2} per second. Calculate the contact time period.

olution:

Now, 99.70% of bacteria are killed i.e. 0.3% of bacteria remains n the water after ozonisation.

In the water, the concentration of bacteria is 100 mg/l and after zonisation, it is 0.30 mg/l. But residual of 0.60 mg/l is given.

N_o = Number of organisms initially

$$= 100 \times \frac{0.60}{0.30} = 200 \text{ mg/l}$$

N_t = Number of organisms at time t

$$= 0.60 \text{ mg/l.}$$

Now,

$$t = \frac{1}{K}\log_{10}\frac{N_o}{N_t}$$

$$= \frac{1}{3\times10^{-2}}\log_{10}\frac{200}{0.60} = 84 \text{ seconds.}$$

The process of hypo-chlorination is carried out at present by commercial compounds such as HTH (high test hypochlorite), Pittchlor, Pittcide, Hoodchlor, Perchloron, etc. instead of bleaching powder.

These compounds have a chlorine content of about 65 to 70 per cent. The other *advantages* of such compounds are as follows:

(i) They are available in powder form in small packings.

(ii) Their chlorine content does not decrease with storage.

(iii) They can be applied to the water in dry condition or as solution.

The process of hypo-chlorination is not adopted for public water supply projects. It may however be adopted for small installations such as swimming pools, etc.

Problem 9-3.

A town having population of about 50000 is to be supplied water at the rate of 150 litres per capita per day. The disinfection of water is to be carried out with bleaching powder containing 30 per cent of active chlorine. If the chlorine dose required for infection is 0.3 p.p.m. or 0.3 mg/l, calculate the quantity of bleaching powder per year.

Solution:

$$\text{Total requirement of water} = (150 \times 50000) \text{ litres/day}$$
$$= 7.5 \times 10^6 \text{ litres/day}$$

$$\text{Chlorine dose required for disinfection} = 0.3 \text{ mg/l}$$

$$\therefore \quad \text{Quantity of chlorine required} = 0.3 \times \frac{7.5 \times 10^6}{10^6} \text{ kg/day}$$
$$= 2.25 \text{ kg/day.}$$

Now, the bleaching powder contains 30 per cent of active chlorine. It means that 30 kg of chlorine is available from 100 kg of bleaching powder.

$$\therefore \text{ Quantity of bleaching powder required} = \frac{2.25}{30} \times 100 \text{ kg/day}$$
$$= 7.5 \text{ kg/day.}$$

$$\text{Requirement of bleaching powder per year} = (365 \times 7.5) \text{ kg}$$
$$= 2737.5 \text{ kg, say } 2750 \text{ kg.}$$

(2) *Chloramines:* It is found that chlorine alone is not stable in water. But when it is mixed in water with ammonia, it forms compounds,

known as the *chloramines*. These compounds are stable in water and are found to possess disinfecting properties. They also remove odour from water to a certain extent. Following are the reactions involved:

$$H_2O + Cl_2 = HCl + HOCl$$
$$NH_3 + HOCl = H_2O + NH_2Cl \text{ (Monochloramine)}$$
$$NH_2Cl + HOCl = H_2O + NHCl_2 \text{ (Dichloramine)}$$
$$NHCl_2 + HOCl = H_2O + NCl_3 \text{ (Nitrogen trichloride).}$$

The monochloramine NH_2Cl predominates at pH value over 7.50; dichloramine $NHCl_2$ at pH of 5 to 6.50; and nitrogen trichloride NCl_3 at pH below 4.40.

The ammonia is added to the water generally in the ratio of one-half to one-fourth of chlorine amount. The ammonia dissolves quickly in water. But it does not diffuse easily in water. Hence it is necessary to mix it with the help of mechanical means. The ammonia may be used in the form of gas or as solution or as ammonium sulphate or as ammonium chloride.

One precaution is necessary when water is treated with the chloramines. The water, after treatment is completed, should be supplied to the consumers after an interval of about 20 to 60 minutes.

Following are the *advantages* of adding ammonia to the water before the addition of chlorine:

(i) It is more effective than chlorine alone.

(ii) The effect produced lasts for a longer period.

(iii) The quantity of chlorine required becomes less.

(iv) There is less irritation to nose and eyes. Hence it is more useful for treating water for swimming pools.

(v) There is no danger of overdose.

(3) *Free chlorine gas:* The chlorine can be applied in gaseous form or in liquid form. In the former case, the chlorine gas is dissolved in a small quantity of water and then the solution is fed to the water under treatment of disinfection. In the latter case, the chlorine gas is converted into liquid form by applying pressure on it. It is found that the chlorine gas when subjected to a pressure of about 0.7 N/mm^2 is converted into liquid. The pressure will however depend on the temperature.

The liquid chlorine is stored in pressure cylinders or drums and is supplied for use. The liquid chlorine is highly corrosive when damp by the simple method of aeration or exposure to sunshine. But this is not a practical or desirable measure for final waters which are intended for public supply purposes.

Problem 9-4.

The quantity of chlorine used to treat 20000 m^3 of water per day is 8 kg. The residual chlorine after contact period of 10 minutes is found to be 0.20 mg/l. Calculate the dosage in mg/l and the chlorine demand of the water.

Solution:

$$\text{Water treated per day} = 20000 \text{ m}^3 = 20000 \times 10^3 \text{ litres} = 20 \times 10^6 \text{ ml.}$$

$$\text{Chlorine consumed per day} = 8 \text{ kg} = 8 \times 10^6 \text{ mg}$$

$$\therefore \text{ Chlorine used per litre of water} = \frac{8 \times 10^6}{20 \times 10^6} = 0.40 \text{ mg/l.}$$

The given chlorine dosage is therefore 0.40 mg/1.

Now, Residual chlorine left = 0.20 mg/l.

Hence the actual chlorine dosage which has reacted in water i.e. the chlorine demand of water is equal to (0.40 − 0.20) = 0.20 mg/l.

Problem 9-5.

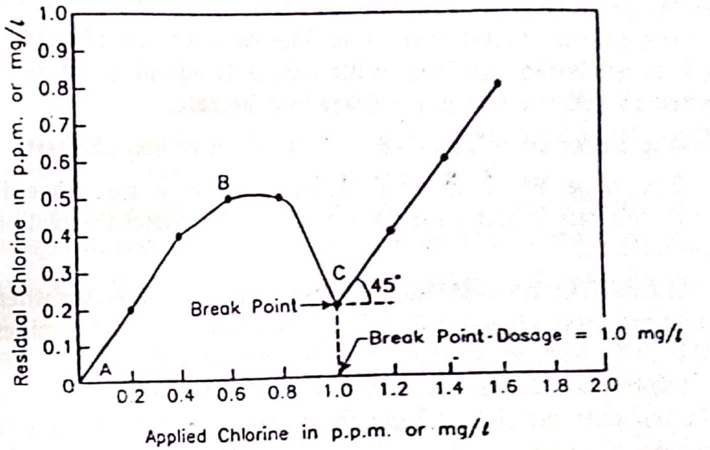
The results obtained from chlorine demand test on samples of raw water are as follows:

Sample no.	Chlorine dosage in mg/l	Residual chlorine after 10 minutes in mg/l
1	0.20	0.19
2	0.40	0.36
3	0.60	0.50
4	0.80	0.48
5	1.00	0.20
6	1.20	0.40
7	1.40	0.60
8	1.60	0.80

Draw the chlorine demand curve and find out the break point dosage. Also calculate the chlorine demand at a dosage of 1.20 mg/l.

Solution:

The chlorine demand curve or in the strict sense, the chlorine residual curve is drawn as shown in fig. 9-2. The break point is represented by point *C* and hence the break point dosage is 1.00 mg/l.



Break point chlorination

FIG. 9-2

Then, $\left.\begin{array}{r}\text{Chlorine demand at} \\ \text{break point}\end{array}\right\} = \text{Applied chlorine} - \text{Residual chlorine}$

$= (1.00 - 0.20) = 0.80$ mg/l.

The chlorine demand after the break point becomes constant and all added chlorine subsequently appears as free chlorine.

$\therefore$ $\left.\begin{array}{l}\text{Chlorine demand at a} \\ \text{dosage of 1.20 mg/l}\end{array}\right\} = 0.80$ mg/l.

Note. The result is in line with given data of chlorine residual of 0.40 mg/l with a dosage of 1.20 mg/l giving the chlorine demand of (1.20 − 0.40) = 0.80 mg/l.

Tests for chlorine:

Following are the usual tests which are applied for determining the amount of free and combined chlorine in a sample of water:

(1) Orthotolidin test

(2) Starch-iodide test.

The orthotolidin test is very common and as the starch-iodide test is costly and time consuming, it is adopted only when the orthotolidin test becomes unsuitable.

Problem 9·2. 15

Compare the contact times necessary to obtain 99.99% kill of bacteria in water under the following conditions:

(1) Free chlorine residual of 0.15 mg/l and $K = 1.1 \times 10^{-2}$ per second.

(2) Combined chlorine residual of 2 mg/l with $K = 1.2 \times 10^{-5}$ per second.

Solution:

(1) *Free chlorine residual:*

The bacteria to be killed are 99.99% i.e. 0.01% bacteria remain in water.

$\therefore$ 0.01 mg/l bacteria remain from 100 mg/l of its concentration.

$\therefore$ 0.15 mg/l bacteria remain from $100 \times \frac{0.15}{0.01} = 1500$ mg/l concentration.

Thus, $N_0 = 1500$ mg/l;

$N_t = 0.15$ mg/l

and $K = 1.1 \times 10^{-2}$ per second.

$$\text{Then,} \quad t = \sqrt{\frac{2}{K} \log_{10} \frac{N_0}{N_t}} = \sqrt{\frac{2}{1.1 \times 10^{-2}} \log_{10} \frac{1500}{0.15}}$$

$$= 26.97, \text{ say } 27 \text{ seconds.}$$

(2) *Combined chlorine residual:*

In this case,

$N_t = 2.00$ mg/l

$K = 1.2 \times 10^{-5}$ per second

$$N_0 = 100 \times \frac{2.00}{0.01}$$

$$= 20000 \text{ mg/l.}$$

$$\text{Then,} \quad t = \sqrt{\frac{2}{K} \log_{10} \frac{N_0}{N_t}} = \sqrt{\frac{2}{1.2 \times 10^{-5}} \log_{10} \frac{20000}{2.00}}$$

$$= 816.50 \text{ seconds.}$$

Minor methods of disinfection:

Following are the seven minor methods of disinfection:

(1) Boiling method

(2) Excess lime treatment

(3) Iodine and bromine treatment

(4) Ozone treatment

(5) Potassium permanganate

(6) Silver treatment

(7) Ultra-violet ray treatment.

Each of the above minor method of disinfection will now be briefly escribed.

(1) ***Boiling method:*** When the water is boiled above a certain emperature, the bacteria are killed. The boiling of water is the most ffective method of disinfection. But to boil water on a large scale s impracticable. However, in case of epidemic, the consumers may e advised to boil the water before use for drinking and domestic urposes as the boiling of water is an absolute safeguard against nfection by bacteria of the water-borne diseases. Most of these bacteria re destroyed when the water has attained a temperature of about 0°C, but it is safer to raise the temperature to boiling. However will only be sufficient to bring the water to the boiling level and rolonged boiling is unnecessary and wasteful.

(2) ***Excess lime treatment:*** The treatment of lime is given to the vater for the removal of dissolved salts. But it was found that if xcess lime is added to the water, it will also work in addition as disinfecting material. The action of excess lime is based on the act that lime increases pH value of water. The extreme acidity or lkalinity is detrimental to bacteria. Hence, when pH value of water s about 9.50 or so, the bacteria can be removed to the extent of 9.93 or 100 per cent. But when this treatment is adopted for isinfection, the excess lime is to be removed by any suitable method f recarbonation after disinfection.

(3) ***Iodine and bromine treatment:*** When water is treated with odine or bromine, it is disinfected. The dosage of iodine or bromine s about 8 p.p.m. and the contact period with water is about 5 minutes. he iodine and bromine are also available in the form of pellets or mall pills. The use of iodine or bromine is limited to small water upplies such as swimming pools, troops of army, private plants, etc.

$$^{P}f={}^{P}P(1+r)^{n} \qquad (2.7)$$

where ^{P}f =future population

^{P}P =present population

r = probable rate of yearly or per decade increase

n =number of years to be considered.

When the population data of the past decades are available the average value of r can be computed from the following expression

$$r=\sqrt[n]{\frac{P_2}{P_1}}-1$$

where P_1 and P_2 are the population data at two dates of n number of years.

This method should be used carefully as it may give erroneously high results when applied to young and rapidly advancing cities having expansion of short duration only. This method is also known as the Geometrical Progression method.

Example : The population of a city was 124,000 in 1960 and 156,000 in 1970. (a) What was the annual rate of increase? (b) What will be the probable population in 1980?

Solution: (a) Here, P_1= 124,000, P_2= 156,000 and n= 10.

$$r=\sqrt[10]{\frac{156{,}000}{124{,}000}}-1=1.023-1=0.023$$

(b) In this case, P_p =156,000, r=0.023, and n=20

P_f =156.000 $(1+0.023)^{20}$=246.000 Ans:

(7) **Least Square Parabola Method**: In this method, the population-time curve is assumed to be parabolic.

Let the variables X and Y denote respectively the year and the population during that year. The equation of the least square parabola fitting the data (census data for a number of decades) is

$$Y=a+bX+cX^2 \quad \text{..........} \quad (2.9)$$

where a, b and c are constants and are to be found from the following normal equations by applying the actual data :

$$\Sigma Y=aN+b\Sigma X+c\Sigma X^2 \quad \text{..........} \quad (2.10)$$

$$\Sigma XY=a\Sigma X+b\Sigma X^2+c\Sigma X^3 \quad \text{..........} \quad (2.11)$$

$$\Sigma X^2Y=a\Sigma X^2+b\Sigma X^3+c\Sigma X^4 \quad \text{..........} \quad (2\ 12)$$

where N = number of observations or sets of data.

If the population data of the city under study for a number of decades are known, then by solving the simultaneous Eqs. 2.10, 2.11 and 2.12 with the given data, the values of the constants a, b, and c in the Eq. 2.9 can be computed, and the desired equation of the least square parabola can be found out. Then from this equation, the population at any future date can be computed.

$$P=\frac{HQ}{3.960} \quad ....(5.1)$$

in which P= theoretical horsepower required to operate the pump (W.H.P. = Water Horse Power):

H = total lift or head of the pump:

Q = volume of water to be pumped. gpm.

If the head to be pumped against is given in psi. the formula becomes.

$$P=\frac{QP}{1.715} \quad ....(5.2)$$

in which P = intensity of pressure. psi.

The actual horsepower required depends on the efficiency of the pump and may be found by relation.

$$P_1=\frac{P}{E} \quad ....(5.3)$$

in which P_1 = actual horsepower required to operate the pump (B.H. P = Break Horse Power)

E = efficiency of the pump.

PROBLEM 1 : It is required to pump water at the rate of 6.750 gpm from a reservoir whose surface is at an elevation of 180 ft. to a tank whose bottom is at an elevation of 372 ft. The pump is placed at an elevation σf 192 ft.. the diameter of the suction pipe is 30 inch. the length of the pipe from the pump to the tank is 290ft. and the estimated size of this pipe is 24 inch. The sum of tbe minor head losses in the suction and discharge pipe may be taken as 1.5 ft. If the maximum

depth of water in the tank is to be 25 ft., what is the required horsepower of a pump for which the overall efficiency is 67 per cent ?

Assume head loss due to friction in 290 ft.+1.5 ft.

Neglect all other head losses.

Solution :

Elevation of water surface in the tank = 372 + 25=397 ft.

Discharge lift or the vertical distance from the centre of the pump to that surface =397 -192 =205 ft.

Suction lift. or the vertical distance from the water surface in the reservoir to the centre of the pump = 192-180 = 12 ft.

Since that pump is above the water surface this lift a positive.

Total head H = 205+12+1.5+1.5 = 220 ft.

$$P=\frac{HQ}{3.960}=\frac{220\times 6.750}{3.960}=375(\text{W.H.P})$$

$$P_1=\frac{375}{0.67}=560(BHP)Ans$$

PROBLEM 2 : Design a suitable set of pumping unit to deliver 4.50.000 gph from an intake well of a river bank to the treatment plant. Total length of rising main from the intake well to the treatment plant is 800ft. and the static head is 60 ft-Design also the cast iron main.

Assume: Velocity of water = 12 fps

friction factor = 0.0075

efficiency = 70%

Solation.

$Q = 4{,}50{,}000 \div 60 = 7.500$ gpm

again $Q = \dfrac{4.50.000}{60 \times 60 \times 6.24} = 20$ cfs

Cross-sectional area $= \dfrac{20}{12} = 1.667$ sq. ft.

$\dfrac{\pi d^2}{4} = 1.667$ (d = diameter of pipe)

$d = \sqrt{\dfrac{1.667 \times 4}{\pi}} = 1.5$ ft =18 inch

Frictional head loss h_f

$= \dfrac{4flv^2}{2gd} = \dfrac{4 \times 0.0075 \times 800 \times (12)^2}{2 \times 32.2 \times 1.5} = 36$ft.

Velocity head, $hv = v^2/2g = (12)^2/2 \times 32.2 = 2.24$ft.

Total head $H = h_S + h_f + h_v = 60 + 36 + 2.24 = 98.24$ ft

$P = \dfrac{HQ}{3{,}960} = \dfrac{98.24 \times 7.500}{3.960} = 188$ (WHP)

$P_1 = \dfrac{180}{0.70} = 265$ (BHP) Ans.

PROBLEM 3 : Water is supplied from an impounding reservoir 30 miles away to a service reservoir near the town. A cast iron main is to be designed to supply 425 mgd. Loss of head due to friction in the pipe is estimated to be 300 ft. All other head looses are neglected. What size cast iron pipe would you use?

Assume f = 0.0075

Solution :

$h_f = \dfrac{4 \times 0.0075 \times (30 \times 5280) \times v^2}{2 \times 32.2 \times d} = 300$

$\dfrac{v^2}{d} = 4.06 \therefore V^2 = 4.06 \times d....1)$

Again. $Q = 425$ mgd $= 425 \times 1.547 = 787$ cfs

[1 mgd = 1.547 cfs]

$Q = av = \dfrac{\pi d^2}{4} \times v \therefore v = \dfrac{4Q}{\pi d}$

$\therefore v^2 = \dfrac{16Q^2}{(\pi d)^2}$

Substituting the value of v^2 from Eq. 2 to Eq. 1.

$\therefore \dfrac{16Q^2}{\pi^2 d^5} = 4.07$

$d^5 = \dfrac{16 \times (787)^2}{\pi^2 \times 4.07^2} = 246.800$

$\therefore d = 11.98 \simeq 12$ft. Ans.

Problem 4 : Design a pumping unit capable of lifting 5 mgd of water from an intake well to the treatment plant against a static head of 60 ft ; length of suction main is 120 ft and that of rising main is 400 ft. The pump will work in two shifts of eight hours each.

Assume : velocity of flow = 6 fps

friction factor = 0.01

efficiency = 75%

Solution :

Total length of pips = 120+400 = 520 ft.

Discharge. Q =5mgd = $\frac{5\times10^6}{6.24} = 8\times10^5$ cu ft/day

Since total pumping time is 16 hrs/day.

Pumping capacity = $\frac{8\times10^5}{16} = 50.000$ cuft/hr.

$$= \frac{50.000}{60\times60} = 13.9 \text{ cfs}$$

$$Q = \frac{\pi d^2}{4} = 13.9$$

$$\therefore d = \sqrt{\frac{4\times13.9}{\pi\times6}} = 1.7 \sim 21.75\text{ft} = 21 \text{ inch}$$

$$h_f = \frac{4\times0.01\times520\times6^2}{2\times32.2\times1.75} = 6.7\,ft$$

$$h_v = \frac{6^2}{2\times32.2} = 0.56\,ft$$

$$H = h_s + h_f + h_v = 60+6.7+0.56 = 67.26\text{ft}$$

$$Q = \frac{50.00.000}{16\times10} = 5.220\,gpm$$

$$P = \frac{HQ}{3.960} = \frac{67.26\times5.220}{3.960} = 88.5 \text{ (WHP)}$$

$$P_1 = \frac{P}{E} = \frac{88.5}{0.75} = 118 \text{ (BHP) Ans.}$$

Problem 5 : Design the transmission main and the pumping unit from the following data :

Water supply rate = 40 gpcd

Estimated population=85.000

Ground R. L. = at the pum house = 102.50 ft.

Treatment plant R. L. = 193.00 ft.

Velocity through pipes = 8 fps

Pumping time = 10 hrs. daily

Total length of pipe = 3.500 ft.

Friction factor = 0.01

Efficiency = 65%

Solution :

Total water required = 40×85.000 =34,00.000 gpd

$$= \frac{34.00.000}{6.24} = 5.45\times10^5 \text{ cuft/day}$$

Pumping rate = $\frac{5.45\times10^5}{10} = 5.45\times10^5$ cuft/day

$$= \frac{5.45\times10^5}{60\times60} = 15.15 \text{ cfs}$$

$$Q = \frac{\pi d^2}{4} = \times v = 15.15$$

$$\therefore d = \sqrt{\frac{4\times15.15}{\pi\times8}} = 1.56 \text{ ft.}$$

Use a 21 inch diameter pipe d = 1.75 ft.

Static head = 193.00 -102.50 = 90.50

Friction head = $\frac{4\times0.01\times3.00\times8^2}{2\times32.2\times1.75}$ =80.0 ft

Velocity head= $\frac{v8^{2}}{2\times32.2}$ 1.0 ft

Total head, $H = 90.5+80.0+1.0=171.5$ft

Discharge, $Q = \frac{34,00,000}{10 \times 60} = 5,667$ gpm

$$\therefore P = \frac{HQ}{3,960} = \frac{171.5 \times 5667}{3,960} = 246 \text{ (WHP)}$$

$$\therefore P_1 = \frac{P}{E} = \frac{246}{0.65} = 380 \text{ (BHP) Ans.}$$

QUESTIONS

1. State the purposes or pumps and pumping machinery in water supply systems.

   Water supply to a small town with ultimate population of one lakh (1,00,000) supplied with 60 gped has to be arranged from a river flowing nearby. Design the economical section of the rising main and the necessary pumping unit from the following data;

Static head	60 ft
Total length of pipe	520 ft.
Coefficient of friction	0.01
Velocity of water in the pipe	6 ft/sec
Pump efficiency	70%

   The pumps will work in two shifts of six hours each in a day. (BUET, 1972)

2. Write the characteristics of centrifugal pumps. Design a suitable pumping unit and the size of the transmission main delivering water from a source 500 yds. away to a treatment plant or a small town having the design. Population of 2.5 millions supplied with 50 gpcd against a frictional head of 70ft. The pump will operate only 8 hrs. in a day. Take pump efficiency =65% and f= 0.01. Neglect all other head losses. (BUET, '71).

3. State the general considerations for pumping installation. What is the theoretical horsepower required for a pump to

raise 1800 gpm of water against a total head of 150 ft. including all losses ?

Which type of pump do you suggest and why? (BUET, '68)

4. What is the total lift of a pump ?

Design a pumping unit to transmit water from a source to a treatment plant of a snail town Having ultimate oppulation of 80,000 supplied with 50 gped of water.

Given : R. L. of the ground at pump hours = 98.20 ft.

R. L. of the entry site ground to a treatment plant = 154.60ft.

Length of pipe line = 2000ft.

Velocity of water through the pipe = 8 fps.

Friction factor = 0.0075

Pump efficiency = 65% (BUET, '67)

5. A multistoried building requires 15,000 gpd of water. The water will be supplied by a 3 inch diameter well. Design a suitable pumping unit from the following data : Suction head =12 ft. Delivery head= 180 ft. Size of the suction and delivery pipe = 2 inch Velocity of water through pipes = 6 ft/sec. Friction factor = 0.01 Assume reasonable values of data not supplied. (BUET, 1972)

6. Write explanatory notes on :

Deep well turbine Pump, Air Lift Pump, Submersible pump. Suction lift.

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then $\frac{Q}{A} =$
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A typical rectangular sedimentation tank is shown in Fig. 8.3.

Example 1 : One million gallons of water per day (1 mgd) passes through a sedimentation tank which is 20 ft. wide, 50 ft. long, and 10 ft. deep, (a) Find the detention time for this basin. (b) What is the average velocity of flow through the basin? (e) If the suspended solids content of the water averages 40 ppm, what weight of dry solids will be deposited every 24 hours assuming 75% removal in the basin, (d) What is the over flow rate?

Solution : (a) Detention time = $\dfrac{\text{Volume of tank}}{\text{Flow per unit time}}$

$$= \frac{20 \times 50 \times 10}{1 \times 106} \times 7.48 \times 24$$

$= 1.8$ hrs.

(b) Velocity, $V_S = \dfrac{Q}{A} = \dfrac{1 \times 10^6}{20 \times 10 \times 7.48 \times 60 \times 60 \times 24}$

$= 0.0077$ fps.

(c) Totat solids deposited $= \dfrac{40 \times 10^6}{10_6} \times 8.34 \times 0.75$

$= 250$ lb/day

(d) Over flow rate $= \dfrac{Q}{BL} = \dfrac{1 \times 10^6}{50 \times 20} = 1000 gpd / sft.$

Example 2 : A rectangular sedimentation tank is to treat 4,00,00 gpd of raw water. The detention period is to be 4 hours, 'the velocity of flow 3 inch per minute and the depth of water and sediment is 14 ft. If an allowance of 4 ft. for sediment is made, what should be the length and width of the sedimentation tank?

Solution :

Velocity of flow = 3 inch/min–0.25 fpm

Total length of the tank =240 × 0.25×60 ft.

Volume of watér to be treated in

$$4 \text{ hours} = \frac{4{,}00{,}000 \times 4}{24} = 66{,}700 \text{ gallons}$$

$$= 8{,}920 \text{ cft.}$$

Cross-sectional area of the tank

$$= 8{,}920/60 = 148.7 \text{ sft.}$$

Effective depth of the tank- 14-4 =10 ft.

Width of the tank= 148.7/10= 14.87= 15 ft.

Circular Sedimentation Tank: Sometimes, circular sedimentation tanks are used, as shown in Fig. 8.4. The diameter of the circular tank depends on the overflow rate, volume and depth. As for circular tanks, equipment is made in certain standard sizes, generally, the tank bottom is cone-shaped with a slope of about 1 inch vertical in 1ft. horizontal. With these conditions as basin the volume of circular sedimention tank is found by the formula

$$V=D^2 (0.011D+0.786H)$$

in which V = volume of circular tank in cft

D = diameter of the tank in ft

The filter beds are usually rectangular in size, having the ratio of length and breadth as 3 : 2.

Example 1 : A rapid sand filterplant is to be designed for a capacity of 6 mgd. What should be the number and size of the filter units? What should be the percentage of filtered water required to wash the filter beds? What should be the capacity of wash water tank?

Assume: (1) Rate of filtration : 2 gpm per sq. ft.

(2) Rate of washing : 15 gpm per sq. ft.

(3) Length of filter run : 24 hrs including 5 min for washing the filter bed and 10 min for resettlement of sands.

Solution :

(a) The plant will operate only 23 hr and 45 min.

Filtration rate = 2×60×23.75=2850 gallons per day per sq ft.

Filter area required = (6.000.000/2,850)=2.100 sq ft.

No. of units. $N=2.7\sqrt{Q}=2.7\sqrt{6}=7$

Area of each units =2100/7 = 300 sq ft.

Size of each unit = 20' × 15'

(b) Total wash water required=15×2100×5= 157,500 gallons per day

Percentage of filtered water required =(157,500/6,000,000) ×100 = 2.625%

(c) Capacity of wash water tank-1,57.500 gallons.

Example 2 : A filter bed has an area of 360 sq ft. If the washing for 5 min at the rate of 24 inch per min is contemplated, how much wash water will be required?

Solution : 24 inch rise of water is attained by applying the wash water at the rate of 15 gpm per sq ft of filter area. Wash water requirement-15 × 360×5=27,000 gallons.

Example 3 : A rapid sand filter operating at 2 gpm per sq ft needs washing after 24 hr of operation. The filter has an area of 350 sq ft and it needs washing at the rate of 15 gpm per sq ft for 5 min. The time required for resettlement of sand is 10 minutes.

What per cent of the water that is filtered will be required for wash water.

Solution : Filtration rate = 2x60 ×23.75=2,850 gpd ped sq ft. Capacity of the plant=2,850×350=997,5000 gpd. Wash water requirement=15×5×350=26,250 gpd percent of filtered water for washing the filter=(26,250/997.500) × 100=2.63

Efficiency of Rapid Sand Filter: With proper pretreatment of the water, rapid sand filters are applicable for treatment of any surface water. Rapid sand filters are very efficient in removing bacteria, colour, odour, turbidity, iron and manganese. The following are the percentage removal of the above mentioned water quality.

within narrow limits of accuracy. To little chlorine is ineffective, too much may cause tastes and odours. Operation of chlorinator should be automatic so that the amount of chlorine fed to water should be proportional to the volume of flow and the chlorine demand of water.

Chlorine Dosage : The amount of chlorine required to be added to the water supply can be determined in the laboratory by adding varying dosages of chlorine to equal proportions of the waste? sample and finding the amount of residual after a contact period of 10-20 minutes.

Example : It is required to disinfect 5,00,000 gpd of water with 0.3 mg/l of chlorine. If bleaching powder is used (which coatains. $33^{1}/_{3}$ percent of available chlorine), how many pounds of bleaching powder are needed to treat the daily flow of water ?

Solution : Available chlorine in the bleaching powder is $33^{1}/_{3}\%$

$\therefore$ 1 Ib of chlorine is available in 3 lbs of bleaching powder.

Since 1 mg/l of chlorine = 8.34 Ibs of chlorine per million gallons of water.

$\therefore$ Amount of bleaching powder required per million gallon = 3 × 8.34=25-02 lbs.

$\therefore$ Amount of bleaching powder required for a flow of 500,000 gpd and a chlorine dosage of 0.3 mg/l.

$$= 25.02 \times \frac{500,000}{1,000,000} \times 0.3 = 3.75 \text{ lbs}$$

Minimum chlorine Residuals for drinking water at 20°C

pH Valve	6-7	7-8	8-9	9-10
Free available chlorine, mg/l after 10 mins	0.2	0.2	0.4	0.8
Combined available chlorine, mg/l after 60 mins	1.0	1.3	1.5	1.8

Special Methods : Chlorine is generally applied after all other treatments have been given to the water supply. This may be termed as post chlorination and is the standard treatment at all waterworks. There are, however, other special methods of chlorination to be used depending upon the particular purposes to be gained.

(a) Pre-chlorination is the application of chlorine preceding filtration, either added into the suction pipes of raw water pumps or to the water as it enters the mixing basin. Pre-chlorination reduces bacterial load filters resulting in increased filter runs, and oxidizes excessive organic matter thus removing taste and odour.

(b) Double chlorination is the application of chlorine at two points in the treatment process. It is essentially pre-chlorination with an added treatment to the final effluent from the filters. Advantages claimed with this method of chlorination are (i) decrease in the load on filters, (ii) greate