N3

Water Treatment Practice

Gateways to Engineering Studies - Chris Brink

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Icons used in this book

We use different icons to help you work with this book; these are shown in the table below.

Icon	Description	Icon	Description
🎓	Assessment / Activity	🎞	Multimedia
📋	Checklist	✂	Practical
👁	Demonstration/ observation	👨‍🏫	Presentation/ Lecture
?	Did you know?	📖	Read
🔍	Example	⊕	Safety
⚗	Experiment	⛑	Site visit
👥	Group work/ discussions, role-play, etc.	⚠	Take note of
⚙	In the workplace	📝	Theoretical – questions, reports, case studies, etc.
🔑	Keywords	💡	Think about it

Module 1

International Metric System

Learning Outcomes
On the completion of this module the student must be able to:

- Describe the SI (Systeme International d'Units)
  - SI base units
  - derived units formed by multiplication and division
  - derived units with special names
  - preferred SI prefixes
  - other units in practice
- Apply the SI
  - gravitational force
  - force
  - amount of work
  - power
  - pressure
  - relative density
  - density
  - heat
- Perform elementary calculations
  - Rounding off numbers and decimal comma
  - simple equations
- Calculate formulae
  - Calculation of area
  - Calculation of volume
- Use different units in volumetric measurement
  - Small and large volumes
- Explain general tips in calculating
- Draw graphs
- Understand concentrations
  - Relationship between percentages

1.1 Introduction

In this module only the SI units of importance to water treatment operators will be discussed. The aim of introducing the SI system is to provide a universal language of measurement in order to standardise all measurements. It is thus of utmost importance that the different units are used correctly.

1.2 The SI (System International d'Units)

1.2.1 SI base units

These units are called base units and the whole structure of the SI is built from them. For each physical quantity there is only one SI unit of which the following in **Table 1.1** are the most important:

Quantity	Name	Symbol
length	metre	m
mass	kilogram	kg
time	second	s
electric current	Ampere	A
thermodynamic temperature	Kelvin	K

Table 1.1 SI base units

Definition:
SI unit (Systeme International d'Unites): A complete metric system of units of measurement for scientists.

The fundamental quantities are length (meter) and mass (kilogram) and time (second) and electric current (ampere) and temperature (kelvin) and amount of matter (mole) and luminous intensity (candela).

1.2.2 Derived SI units

Derived units can be divided into 2 groups, namely; units formed by multiplication and division. **Table 1.2** shows important examples to know.

Quantity	Name	Symbol
area	square metre	m^2
volume	cubic metre	m^3
speed, velocity	metre per sec	m/s
density	kg per cub m	kg/ m^3
rotational frequency	revolutions per minute	r/m

Table 1.2 Derived SI units

Important:
Note that r/m is not an SI unit but is accepted.

- **Derived units with special names**

Below, **Table 1.3** shows derived units with special names.

Quantity	Name	Symbol
Force, weight	Newton	N
Energy, work	Joule	J
Heat	Joule	J
Pressure, stress	Pascal	Pa
Power	Watt	W
Electrical potential	Volt	V
Electrical conductivity	Siemens	S

Table 1.3 Derived units with special names

- **Preferred SI prefixes**

Below, **Table 1.4** shows SI prefixes.

Prefix	Meaning	Factor	Symbol
Mega-	million	10^6	M
kilo-	thousand	10^3	k
milli-	thousandth	10^{-3}	m
micro-	millionth	10^{-6}	μ

Table 1.4 Preferred SI prefixes

1.2.3 Other units used in practice

Certain other units are also accepted, although they are not SI units and include what is shown in **Table 1.5** below.

Quantity	Name	Symbol
time	minute, hour, day	min, h, d
mass	metric ton	t
volume	litre	l
speed	kilometre per hour	km/h
area	hectare	ha
temperature	degress Celcius	°C

Table 1.5 Other units

1.3 Application of the SI

1.3.1 Gravitational force

The acceleration caused by the gravitational force which is exercised by the earth on a falling body or object is given by the symbol "g", which may be taken as about 10 metre per second per second (m/s^2).

Normally "g" differs on different places on the earth.

1.3.2 Force

Force is exercised when an object is pushed or pulled and is directly proportional to the mass of a body and the force of gravity. It can be represented by the following formula:

Force = mass x acceleration
= m x g
= kg x mjs2
= Newton

1.3.3 Amount of work

The amount of work done can be defined as the amount of energy spent to move an object over a certain distance. It can be represented by the following formula:

Amount of work = force x distance moved
= N x m
= Joule

1.3.4 Power

Power can be defined as the rate at which work is done. It can be represented by the following formula:

Power $= \frac{\text{amount of work}}{\text{time}}$
= Joule/second
= Watt

1.3.5 Pressure

Pressure is the force exerted on a unit surface area. It can be represented by the following formula:

Pressure $= \frac{\text{force}}{\text{surface area}}$
= Newton/m^2
= Pascal

On the next page, **Worked Example 1** shows a pressure calculation.

Worked Example 1

Calculate the pressure which will be exercised by a beam 250 m in length and 100 mm wide resting on the floor. The mass of the beam is 50 kg.

Pressure $= \frac{\text{force}}{\text{surface area}}$

$= \frac{50\ \text{kg x } 10\ \text{m/s}^2}{250\ \text{m x } 0{,}1\ \text{m}}$

$= \frac{500\ \text{N}}{25\ \text{m}^2}$

= 20 Pa

- **Pressure in terms of a liquid**

Due to a difference in density of substances and the head, the basic formula P $= \frac{\text{f}}{\text{a}}$ changes as follows:

Pressure = density x gravity x head in metre
= p x g x h
= kg/m^3 x m/s^2 x m
= N/m^2
= Pascal

A calculation with pressure in terms of liquid is done in **Worked Example 2**.

Worked Example 2

Calculate the pressure per unit area exercised by water at a depth of 1 m.

Pressure = density x gravity x head
= 1 000 kg/m^3 x 10 m/s^2 x 1 m
= 10 000 Pa
= 10 kPa

1.3.6 Density

The density of a substance is calculated by means of the following formula:

Density $= \frac{\text{mass (kg)}}{\text{volume (m}^3\text{)}}$

A density calculation is done in **Worked Example 3** on the following page for you to follow.

Worked Example 3

Calculate the density of one cubic metre of water.

1 m^3 of water = 1 000 litre with a mass of 1 000 kg.

Density $= \frac{1\ 000 \text{ kg}}{1 \text{ m}^3}$

$= 1\ 000 \text{ kg/m}^3$

1.3.7 Relative density

This density is calculated relative to the density of another substance. The same basic formula applies here.

Relative density $= \frac{\text{mass}}{\text{volume}}$

Relative density calculations are done in **Worked Examples 4** and **5** below.

Worked Example 4

The mass of 1 000 ml of gasoline is 900 g.

Calculate the relative density.

Relative density $= \frac{\text{mass}}{\text{volume}}$

$= \frac{900 \text{ g}}{1\ 000 \text{ ml}}$

$= 0{,}9 \text{ g/ml}$

This means that the mass of 1 ml of gasoline is 0,9 g.

Worked Example 5

A stone weighing 450 g is placed in a 1 000 ml measuring cylinder containing 300 ml water. The water level now rises to 620 ml. Calculate the relative density of the stone.

Relative density $= \frac{\text{mass}}{\text{volume}}$

$= \frac{450 \text{ g}}{620 \text{ ml} - 300 \text{ ml}}$

$= 1{,}41 \text{ g/ml or } 1{,}41 \text{ kg/l}$

Important:
1 ml of water has a mass of 1 g.
Thus if the relative density of the stone is calculated as 1,41, it means that the stone is 1,41 times heavier than water.

1.3.8 Density and heat

Relative density is specified at a temperature of 20°C. An increase in temperature will increase the volume of the object (due to expansion) and will therefore decrease the relative density and vice versa.

Water, however, reaches its maximum density at 4°C.

1.4 Elementary calculations

1.4.1 Rounding off numbers and decimal comma

In rounding off to the nearest 100, we look at the tens. If it is 5 or more, we add 1 to the hundreds and put zeros for everything less than 100.

Below **Worked Examples 6, 7** and **8** show examples of rounding off numbers and decimal comma.

Worked Example 6

Round off 7236 to the nearest 100. Look at the tens digit i.e. 3, it is less than 5. Thus the answer is 7200 (7236 is closer to 7200 than to 7300).

Worked Example 7

Round off 82346 to the nearest 10. Look at the one's digit, i.e. 6. It is more than 5. Thus the answer is 82350 as it is closer than 82340.

Worked Example 8

Round off 2,3765 off to:

i) the nearest whole number : 2
ii) the nearest tenth : 2,4
iii) 2 decimal places 2,38
iv) 3 decimal places 2,377

1.4.2 Conversion of decimal fractions to common fractions

Let us now examine the conversion of decimal fractions to common fractions and vice versa.

- **Decimal to common fractions**

Worked Examples 9 and **10** show the conversion of decimal fractions into common fractions.

Worked Example 9

0,3 = $\frac{3}{10}$. The number of places after the decimal comma will tell you how many zeros in the denominator.

Worked Example 10

0,29 = $\frac{29}{100}$. Two decimals, thus denominator is 100.

- **Common to decimal fractions**

Worked Example 11 shows the conversion of common fractions into decimal fractions.

Worked Example 11

$\frac{3}{10}$ = 0,3. The number of zeros in the denominator will tell us how many decimal places.

1.4.3 Simple equations and transposing

Important:
An equation remains true if you do the same thing on each side.

Worked Example 12 shows an example of simple equations and transposing.

Worked Example 12

Solve for p.

$3(p + 1) - 5 = 2p - 5(p - 2)$
$3p + 3 - 5 = 2p - 5p + 10$ (expand brackets)
$3p - 2 = -3p + 10$ (simplify each side)
$3p + 3p = 10 + 2$ (collect terms with p on left, others on right)
$6p = 12$ (simplify)
$p = \frac{12}{6}$ (divide both sides by the coefficient of p)

p = 2

This type of algebra has already been done in N1 and should be known by now. It can also be done as follows:

3p – 2 = -3p + 10 (simplify)
3p + 3p = 10 + 2 (transpose)

Find the roots:

$x^2 = 25$
$x = \sqrt{25}$
$x = +\sqrt{5}$ or $x = -\sqrt{5}$
or $x = \sqrt{5}$

Quadratic equations:

$27x^2 = 75$
$27x^2 = \frac{75}{27}$
$27x^2 = \frac{25}{9}$ (simplify)
$27x^2 = \pm\sqrt{\frac{25}{9}}$

Think about it!

Revise N1 mathematics regarding the following:

- Decimal comma
- Grouping of figures
- Rounding off and significant figures
- Exponential notation
- Example equations and transposing

It is important to know the basics to be able to do these calculations.

1.5 Formulae

You should know the following formulae:

1.5.1 Calculation of area

- **Rectangle**

On the following page, **Figure 1.1** shows a rectangle.

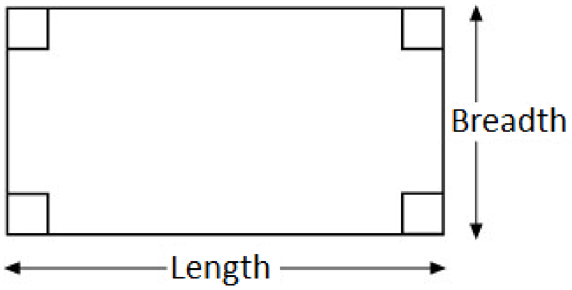


Figure 1.1 Rectangle

Area = length x breadth
= m^2

- **Circle**

Below, **Figure 1.2** shows a circle.

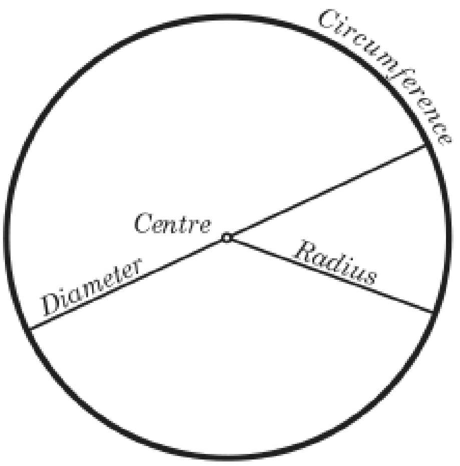


Figure 1.2 Circle

Area $= \pi r^2$
Or Area $= \pi\left(\frac{d^2}{4}\right)$
= m^2
Where r = radius
d = diameter

Pi (π) $= \frac{\text{circumference}}{\text{diameter}}$
$= \frac{22}{7}$
= 3,14

- **Triangle**

On the following page, **Figure 1.3** shows a triangle.

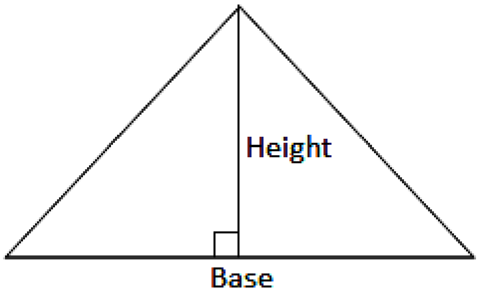


Figure 1.3 Triangle

Area = ½ base x height
= m^2

1.5.2 Calculation of volume

The volume of any container is equal to the area multiplied by the height or depth.

- **Rectangular tank**

Area = Area x height
= length x breadth x height
= m x m x m
= m^3

- **Cylinder**

Below, **Figure 1.4** shows a cylinder.

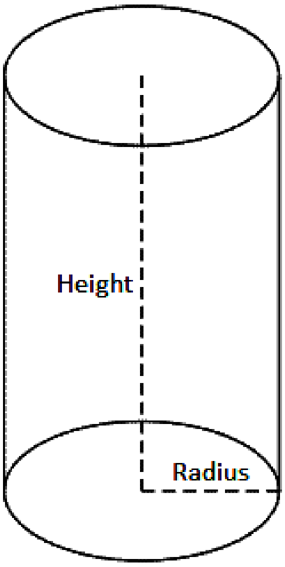


Figure 1.4 Cylinder

Volume = Area x height
= $\pi r^2 \times h$
= m^3

- **Pyramids and cones**

Below, **Figure 1.5** shows a pyramid and cone.

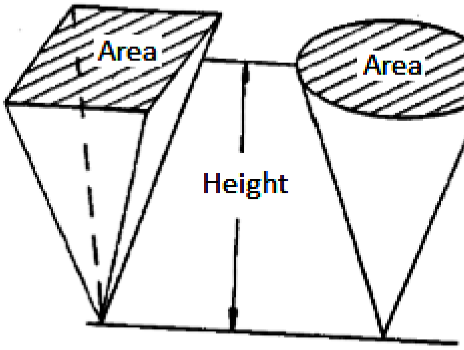


Figure 1.5 Pyramid and cone

Volume $= \frac{1}{3}$ area of base x vertical height

$= m^3$

- **Dortmund sedimentation tanks**

Below, **Figure 1.6** shows a Dortmund sedimentation tank.

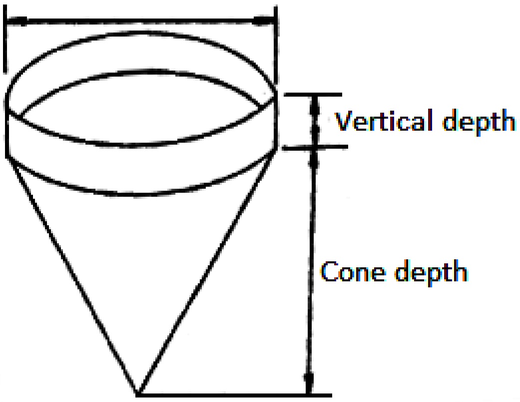


Figure 1.6 Dortmund sedimentation tank

From the schematic drawing it is observed that the tank consists of 2 components:

a) A cylindrical part
b) A cone shaped part

Total volume = volume of cylinder – volume one

$$= \left(\pi\left(\frac{d^2}{4}\right) \text{ x h}\right) + \left(\pi\left(\frac{d^2}{4}\right) \text{ x h x } \frac{1}{3}\right)$$

or

$$= \left(\pi\left(\frac{d^2}{4}\right) \text{ x h}\right) + \left(\pi\left(\frac{d^2}{4}\right) \text{ x h x } \frac{h}{3}\right)$$

1.6 Different units of volume measurement in water industry

According to the SI units, the base unit of length is metre. The correct volume is thus m^3. In certain instances a cubic metre may be too large to serve as volumetric measure, while in other instances it may be too small.

1.6.1 Small volumes

The following measurements are all accepted:

1 mm^3; 1 cm^3 (1 ml); 1 dm^3 (1 litre)

From the basic formula of volume calculation (v = 1 x b x h) the following can be derived:

1 m = 10 dm; 100 cm; 1 000 mm

Figure 1.7 illustrates volume of a rectangle.

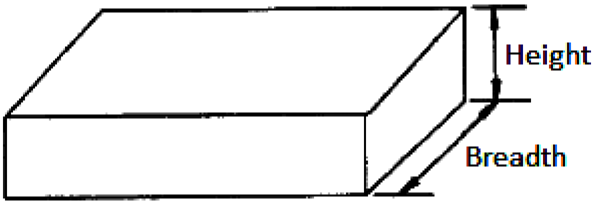


Figure 1.7 Breadth and height of a rectangle

Thus 1 m^3 = 10 dm x 10 dm x 10 dm
= 1 000 dm^3
= 10^3 dm^3 (10^3 litre)

and 1 m^3 = 100 cm x 100 cm x 100 cm
= 1 000 000 cm^3
= 10^6 cm^3 (10^6 ml)

and 1 m^3 = 1 000 mm x 1 000 mm x 1 000 mm
= 1 000 000 000 mm^3
= 10^8 mm^3

Therefore:1 $m^3 \equiv 10^3\ dm^3 \equiv 10^6\ cm^3 \equiv 10^9\ mm^3$

1.6.2 Large volumes

For large volumes the following units are accepted:

Kl; m3; Ml

Important:

When calculating, make use of the following steps:

1. Write down what is given
2. Write down what is asked
3. Write down the correct formula and substitute the given values in the formula
4. Do a rough calculation
5. Do the actual calculation
6. Compare the answer in (d) and (e)
7. If the answers differs much, check for calculation errors

1.7 Graphs

The use of graphs is of great value in water treatment and the student should be able to plot and interpret graphs. Two different sets of figures or data are required to draw a graph.

A graph has 2 axes. One is vertical (y-axis) and the other horizontal (x-axis).

Graphs are used for a great number of purposes:

- to plot flow patterns against time
- pump efficiency
- calibration of dosing apparatus, etc.

Once you understand how to interpret a graph, you may use this principle to illustrate a variety of important information. **Worked Examples 13** and **14** put this principle into action.

Worked Example 13

The flow as measured at the- inlet works was the following over a seven days period. Represent the figures in **Table 1.7** graphically:

Days	**Flow measured (m^3/d)**
1	3 500
2	2 100
3	4 600
4	3 800
5	1 500
6	2 800
7	3 600

Table 1.7

The vertical-axis will represent flow (m³/d) while the x-axis will represent the different days.

Before plotting the graph, decide on a suitable scale e.g. 50 mm = 1 000 m³ of flow on the y-axis and 20 mm = 1 day on the x-axis to plot the graph as large as possible for clear representation of facts.

Plot the values on the graph and combine the points as seen in **Figure 1.8** on the following page.

Graphs can also be represented on a round flow chart or a horizontal flow chart.

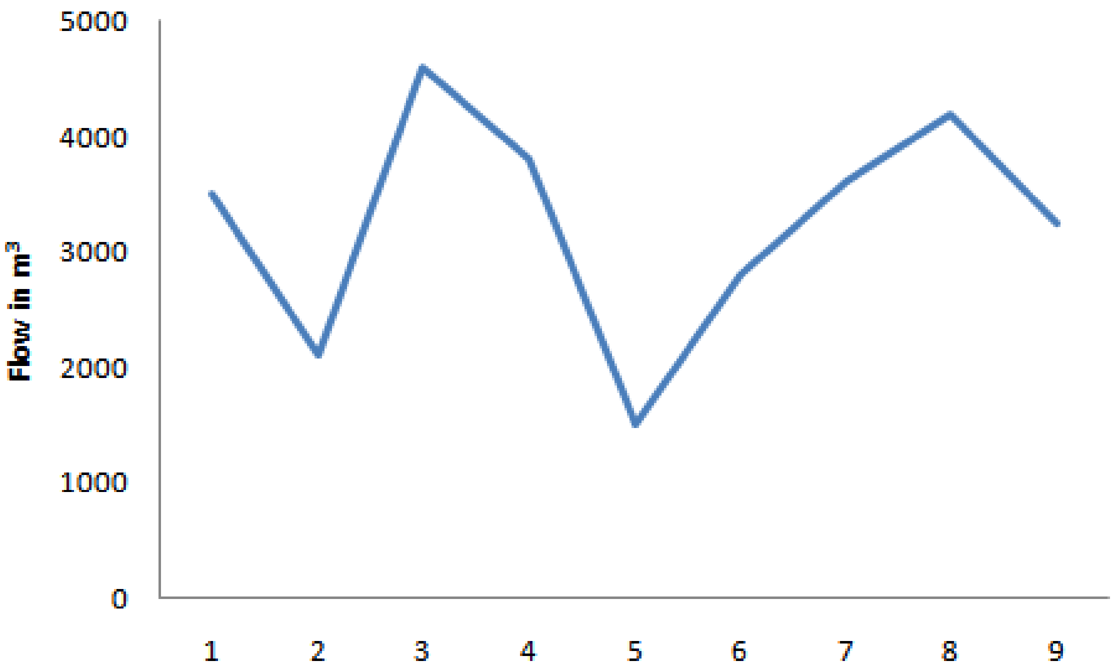


Figure 1.8 Flow in m³/d

Worked Example 14

Plot the relative density of Ferrichloride at 20°C against the % $FeCl_3$ (mass/mass) of a solution used for dosing purposes. The following data in **Table 1.8** is available.

% $FeCl_3$ (m/m) in solution	**Relative density**
5%	1,052
10%	1,09
15%	1,13
20%	1,18

25%	1,235
30%	1,30
35%	1,365
40%	1,45

Table 1.8

The % $FeCl_3$ in solution will be represented on the horizontal-axis while the relative density of $FeCl_3$ will be represented on the vertical-axis. See **Figure 1.9**.

Choose again a suitable scale for the different axes e.g. 20 mm = 5% $FeCl_3$ solution and 20 mm = 0,05 density units.

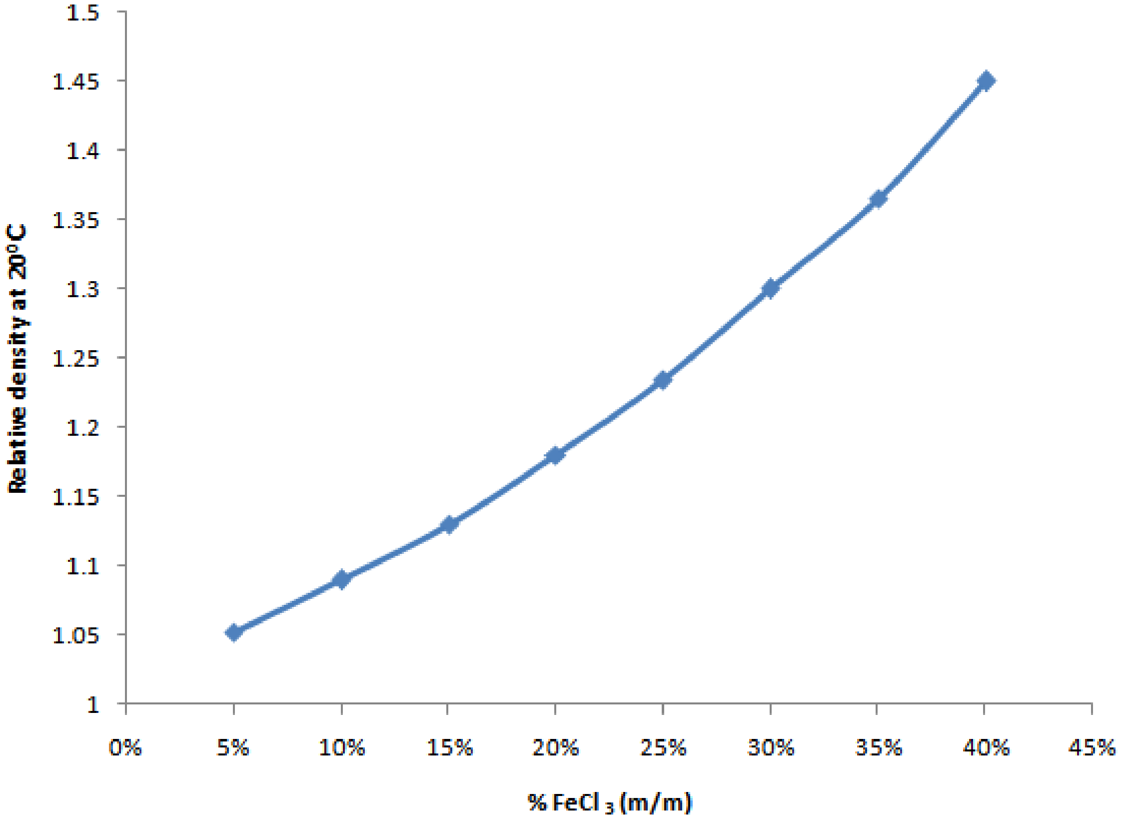


Figure 1.9 Relative density

1.8 Concentrations

The concentration of a solution can be defined as the amount solute per solution. (Solution = solute + solvent). In water treatment, concentrations are usually expressed in the following ways:

- Percentage (m/m) mass per mass
- Percentage (m/v) mass per volume
- Percentage (v/v) volume per volume
- Molar concentration (m) (molars per volume)

- Normality (N) Equivalent solute per liter of solution

Concentration in % merely means parts per hundred. The following are examples:

- % m/m: 20 g lime with 80 g of sand is a 20% m/m mixture of lime
- % m/v: 5 g Al(S04)3 dissolved in water and diluted to 100 ml is a 57% m/v solution
- % v/v: 15 ml alcohol diluted to 100 ml is a 15% v/v solution

When the relative density of the solution is very near to 1,0, it is permissible to take the % (m/v) as equivalent to the % (m/m) and when the relative density of both the substance and the solvent is near to 1,0, the % expressed as m/v, m/m or v/v can all be taken as equivalent. To convert % m/v to m/m, the relative density of the solution must be taken into account.

1.8.1 Relationship between percentages

Lower concentrations are conveniently expressed in mg/l, which is the same as g/kl or g/m^3 and kg/Ml. Thus a 1% (m/v) solution is equivalent to 10 g/kl or 1 000 mg/l.

mg/l $\underline{=}$ g/m^3 $\underline{=}$ kg/Ml

E.g. 10 mg/l$\underline{=}$ 10 g/m^3 $\underline{=}$ 10 kg/Ml

It is very important to understand and know this principle as it can be of great help in calculations.

Activity 1.1

1. If a floodgate lets water at 5 m3, what will the flow be in l/sec?
2. A reservoir has the following dimensions:
   length = 20 m, width = 10 m , depth = 4 m. A pump pumps water to the reservoir at 10l/sec.
   Calculate:
   a) The volume of the reservoir
   b) The time (in hours) it will take to fill up the reservoir.
3. The following information is given at the end of the month at a purification plant. Calculate the percentage water loss.
   a) Purified water pumped from the plant = 325 000 m3
   b) Raw water pumped to the plant = 336 000 m3
4. What are the basic units (SI system) of the following:
   i) mass
   ii) time
   iii) electric current
   iv) temperature

Give an example of a derived unit in each of the above mentioned.

5. Give the formula for calculating the following:
   a) amount of work
   b) pressure in terms of a liquid
   c) relative density

Self-Check

I am able to:	**Yes**	**No**
• Describe the SI (Systeme International d'Units)		
o SI base units		
o derived units formed by multiplication and division		
o derived units with special names		
o preferred SI prefixes		
o other units in practice		
• Apply the SI		
o gravitational force		
o force		
o amount of work		
o power		
o pressure		
o relative density		
o density		
o heat		
• Perform elementary calculations		
o Rounding off numbers and decimal comma		
o simple equations		
• Calculate formulae		
o Calculation of area		
o Calculation of volume		
• Use different units in volumetric measurement		
o Small and large volumes		
• Explain general tips in calculating		
• Draw graphs		
• Understand concentrations		
o Relationship between percentages		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 2

Elementary Hydraulics

Learning Outcomes

When you have completed this module, you should be able to:

- Describe water and other liquids
  - Relative density
  - viscosity
- Explain flow velocity versus flow rate
  - Flow velocity
  - flow rate
- Describe hydrostatic pressure
- Explain pressure-velocity-head relationships
  - Hydraulic gradient
  - other factors
- Explain flow in channels
- Understand the syphon
- Describe flow measurement and measuring

2.1 Introduction

In this module elementary hydraulics is discussed. This includes relative density and viscosity of water and other liquids, hydrostatic pressure, flow in pipes and factors influencing it as well as flow in channels and means of measurement and metering.

On completion of this module you must have a good general knowledge of all abovementioned aspects and be able to convert and do simple calculations regarding flow and density.

2.2 Water and other liquids

The main properties of water With respect to hydraulics are as follows:

- It is incompressible
- Water has a low coefficient of expansion
- The density of water is the greatest at about 4 °C.

2.2.1 Relative density

All matter occupies space and therefore has volume. The density of a liquid is directly proportional to its mass per volume and more energy is thus needed to enable:

- a litre of a more dense liquid to flow at a certain velocity than that required for
- a litre of a less dense fluid to flow at a certain velocity than that required for
- a litre of a less dense fluid to flow at the same velocity.

Density can be calculated according to the following formula:

$$\text{Density } (\rho) = \frac{\text{mass (kg)}}{\text{volume (m}^3\text{)}}$$

Density is specified at a temperature of 20 °C. If the temperature is raised above 20 °C, the volume of the substance will increase due to expansion and therefore the relative density will decrease.

If the temperature is decreased to below 20 °C, the volume will decrease due to contraction and the relative density will increase.

Relative density can also be calculated as in the following example:

Worked Example 1

A piece of stone 450 g is placed in a 1 litre measuring cylinder containing 400 ml water. The level of the water now rises at 750 ml.

$$\begin{aligned}\text{Therefore: Relative density} &= \frac{\text{mass}}{\text{volume}} \\ &= \frac{450\ \text{g}}{750\ \text{ml} - 400\ \text{ml}} \\ &= 1{,}29\end{aligned}$$

It is well known that the mass of 1 ml of water is 1 g. The relative density is thus 1. If the relative density of the stone is calculated as 1,29, it means that the stone is 1,29 times heavier than water.

When water at 0 °C is heated, it contracts until its temperature reaches 4 °C. Further addition of heat and change in molecular structure arrangement leads to gradual expansion and change in density.

This means at a temperature of 4 °C (maximum density) one millilitre (cm^3) of water has a mass of 1 gram.

2.2.2 Viscosity

It is a measure of the forces within a material that resist flow. Flow is induced by a stress or shear placed on the material.

Flow may be explained as a dual process - the movement of molecules in one direction and the movement of the spaces between the molecules (holes) in the opposite direction.

Definition:

Viscosity is a measure of a fluid's resistance to flow. It describes the internal friction of a moving fluid. A fluid with large viscosity resists motion because its molecular makeup gives it a lot of internal friction.

A fluid with low viscosity flows easily because its molecular makeup results in very little friction when it is in motion.

A liquid at room temperature has a smaller number of holes than it has at a higher temperature. Thus viscosity decreases as the temperature increases and differs for different liquids.

The influence of temperature is also much greater on fluids with a high viscosity than on those with a low viscosity.

It is thus obvious that the higher the viscosity, the more difficult the liquid will move through a pipe.

Pressure does not change the density or viscosity of a liquid, it can only change the velocity at which it flows.

2.3 Flow velocity versus flow rate

2.3.1 Flow velocity (v)

Flow velocity of water is the distance covered during a given time period.

$$\text{Velocity} = \frac{\text{distance (m)}}{\text{time (s)}}$$

$$= \text{m/s (also written as m.s}^{-1}\text{)}$$

The velocity of flow from a free falling column of water can also be calculated by the following formula.

$$v = \sqrt{2gH} \text{ m/s}$$

2.3.2 Flowrate (Q)

The rate of flow of water is the volume of water which flows per unit time and can be calculated as follows:

$$Q = \frac{\text{volume (m}^3\text{)}}{\text{time (s)}}$$

$$= \text{m}^3/\text{s}$$

Velocity is given in m/s. To calculate volume, this must be multiplied by cross sectional area (A).

Thus: $Q = A\sqrt{2gH}$ m^3/s
Where: g = gravitational force
H = static head of the water column

This formula is of importance because most measurements of water flow are based on this formula. Friction in pipelines or channels will however influence the flow velocity and must therefore be taken into account.

Friction losses are indicated by the factor "C", and the formula becomes:

$$Q = CA\sqrt{2gH} \text{ m}^3/\text{s}$$

Friction losses (C) vary and depend on the type of pipe, obstructions, nature of internal surface of the pipe, etc. These factors can be obtained from tables supplied by the suppliers of pipes.

2.4 Hydrostatic pressure

The pressure exercised at the bottom of any container, dam, sedimentation tank, sandfilter or a reservoir connected to a pipeline is called the hydrostatic pressure.

This pressure is determined by the height and mass of liquid above a certain point.

Mass per unit volume is referred to as the density of a fluid. The density of water at a temperature of 15 °C and pressure of 1 atmosphere is about 1 000 kg/m^3 (999 kg/m^3).

The force exerted by gravity on 1,0 m^3 of water is thus 10 kN/m^3. (This is equal to the density multiplied by the gravitational acceleration which is 9,81 m/s^2 or usually taken as 10 m/s^2).

Pressure is the force exerted per unit area. In hydraulics, water pressure is frequently expressed in terms of meters of head, as well as kPa.

Water pressure increases in depth below the surface.

Water with a depth of height of 1 m will exercise a pressure of about 10 kPa at the bottom, while water at a depth of height of 2 m will exercise a pressure of about 20 kPa at the bottom.

Furthermore the shape of the container does not play any role on the pressure exercised at the bottom. Pressure is exerted equally in all directions.

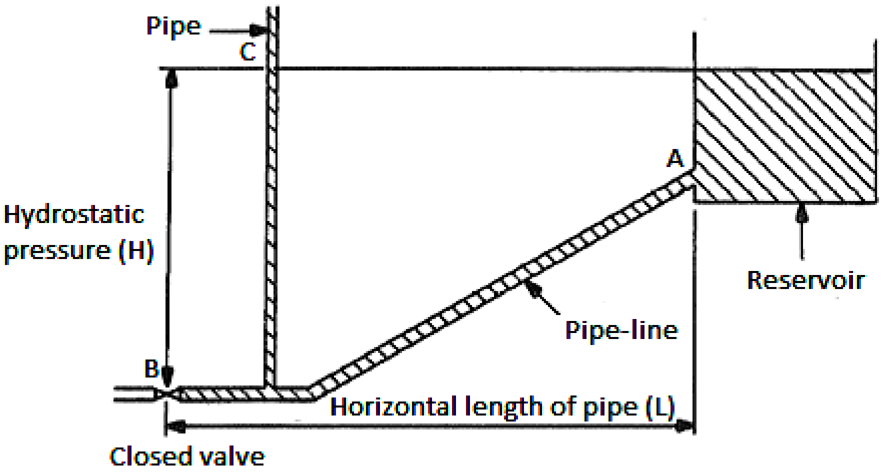


Figure 2.1 Hydrostatic pressure

If the pressure measured is greater than atmospheric this value is sometimes called gauge pressure. If the pressure measured is less than atmospheric, it is referred to as vacuum.

Absolute pressure is the term used for a pressure reading that includes atmospheric pressure; that is the pressure relative to absolute zero.

2.5 Flow in pipes

If water at one surface level is connected to water with a lower surface level, the pressure caused by the difference in head will force the water towards the lower level. This force will only stop when the two levels are equal.

When the valve is opened at the end of a pipeline as in **Figure 2.1** the volume of water obtained at this point will depend on the following factors:

- Head loss
- Hydraulic gradient
- Hydraulic radius of water in the pipe
- Other factors such as roughness in the pipe, bends, valves, obstructions, scale, etc.

2.5.1 Pressure-velocity-head relationships

The association between the quantity of water flow, average velocity and cross-sectional area of flow is given by the equation Q = VA.

For an incompressible fluid such as water, if the cross-sectional area decreases, the flow velocity must increase and vice versa.

The total energy at any point in a hydraulic system is equal to the sum of the elevation head, pressure head and velocity head.

The pressure head is equal to the height to which the water would rise in a piezometer (small tube rising from a container of water under pressure) inserted in the pipe.

The elevation head is equal to the vertical distance from an assumed datum plane to the pipe.

The sum of these two heads is the hydraulic head. The velocity head is equal to kinetic energy in the water flow and when added to the hydraulic head yields total energy.

Energy measured at different points in a piping system will indicate a loss. The major loss is due to friction between the moving water and pipe wall as well as other factors.

The imaginary line connecting all points of total energy is called the energy gradient or grade line.

This line must always slope in the direction of flow, showing a decrease in energy, unless external energy is added to the system for example by means of a pump.

2.5.2 Hydraulic gradient

It can be defined as the line connecting the level of elevation plus pressure energies, this being defined by the water surfaces.

It is thus the ratio between the available head (hydrostatic pressure) and the horizontal length of the pipeline as shown in **Figure 2.1**.

$$\text{Hydraulic gradient} = \frac{\text{available head in m}}{\text{length of pipeline in m}}$$

The hydraulic gradient in a sewer create the "self-cleansing velocity" in the pipeline. To ensure a velocity of about 1 m/s, a hydraulic gradient of 1:40 or 2,5% is needed. This means that a head of 1 m is needed for every 40 m length of pipeline.

2.5.3 Hydraulic radius

It is the "vetted area" in the pipeline, whether the pipe is flowing full or only partially full.

2.5.4 Other factors

Minor losses in pipelines are caused by abrupt changes in the flow geometry as a result of changes in pipe size, bends, valves and fittings of all types.

In long pipelines these minor losses can often be neglected without serious error, but they may be quite important in short pipes.

Minor losses are generally greater where flow decelerates than where an increase in velocity occurs because of eddies created by separation of flow from the conduit boundary.

Losses due to valves, bends, etc. are relatively insignificant in comparison with pipe friction losses.

In the case of pumping stations and treatment plant piping, the minor losses in valves and fittings are significant and constitute a major part in the total losses.

Unit head losses may be expressed as being equivalent to the loss through a certain length of pipe expressed in number of pipe diameters.

2.6 Flow in channels

Open channels may take the form of a canal, flume, tunnel or partly filled pipe.

Open channels are characterised by a free water surface which means that there is no excess pressure to force the water along, it moves under the influence of the difference in head provided by a sloping surface.

Calculations to do with open channels are rather complicated and will not be discussed as it is not important at this stage.

The equation $Q = VA$ still applies, but it must be remembered that the velocity in an open channel is not equal at all points.

It is least next to the walls and floor of the channel and greater just below the surface in the middle of the channel (turbulent flow).

2.7 The syphon

A syphon is a simple apparatus by which a liquid may be moved from one container to another or from one place to another.

When suction is applied at a point of the pipe, the pressure which is due to the atmosphere, forces the water up in the pipe.

Liquid will only be moved if there is a difference in pressure, i.e. the pressure on surface B must be higher than at point A.

Below, in **Figure 2.2**, a syphon is illustrated.

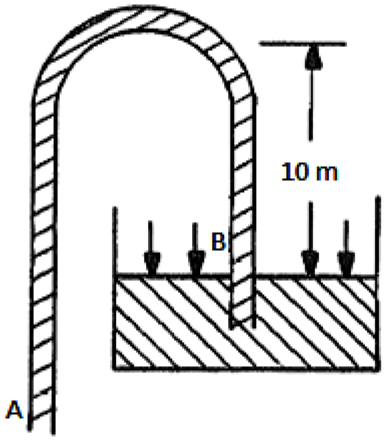


Figure 2.2 Syphon

2.8 Flow measurement and metering

The best way of measuring pipe flow is to time how long it takes to fill a certain volume. Note that flow can be measured by how long it takes to empty a container also. The following devices are used for measuring water:

- Magnetic flow meters - expensive and need skilled maintenance
- Ultrasonic flow meters
- Positive displacement pumps which deliver a fixed amount of liquid on each cycle

The flow in constricted channels can be measured by the use of weirs and venturi-type flumes. A flume is a constriction in the channel such as in **Figure 2.3**.

The narrowing of the flow should force the water to shoot through at high speed and then form a hydraulic jump on the downstream side of the flume.

When this happens, the depth of water in the channel above the flume can be used as an indicator of the rate of flow.

Other methods for measuring flow conveniently are:

- V- notch weir
- Rectangular weir, etc.

⚠	**Important:** Note that for all weirs, the water depth must be measured at a short distance away from the crest.

The principles for the various means of measurement differ greatly.

It is however very important to know and record the flow rate at any purification works.

The proper maintenance and care of any flow meter or recorder is therefore of great importance and an operator should know how to maintain an instrument (cleaning, replace ink, etc.)

Flow can be expressed in cubic meters per second (cumec), litres per second (lisec) or even megalitres per day.

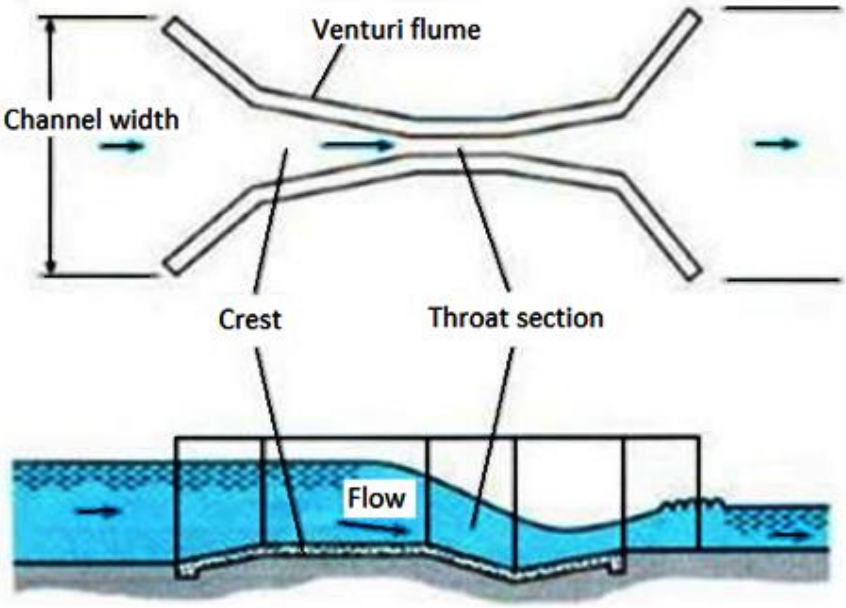


Figure 2.3 Venturi-flume in a channel

Activity 2.1

1. Express a flow rate of 3 cumec in:
    a) litre per second
    b) kilolitre per minute
    c) cubic metre per hour
    d) megalitre per day
2. Calculate the relative density of Ferric chloride with the following given:
    a) Mass of empty volumetric flask = 322,25 g
    b) Mass of flask filled with 1 000 ml Ferric chloride at 20 °C = 1776,25 g
3. Define:
    a) Hydraulic gradient
    b) Hydrostatic pressure
    c) Viscosity
    d) Flow velocity
4. Briefly explain why the density of water is greatest at 4 °C.
5. Give 4 reasons why it is essential to determine the flow through a plant.

Self-Check

I am able to:	**Yes**	**No**
• Describe water and other liquids		
o Relative density		
o Viscosity		
• Explain flow velocity versus flow rate		
o Flow velocity		
o flow rate		
• Describe hydrostatic pressure		
• Explain pressure-velocity-head relationships		
o Hydraulic gradient		
o other factors		
• Explain flow in channels		
• Understand the syphon		
• Describe flow measurement and measuring		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 3

Pumps

Learning Outcomes

When you have completed this module, as a learner you will be able to:

- Describe driving force and power
- Describe pump types and uses
    - o Positive displacement pumps - reciprocating, Archimedean screw, ram pumps
    - o Water hammer, starting and slip
    - o Roto-dynamic pumps, air lift pumps
- Explain the operation and maintenance of pumps and motors
- Describe the selection of pumps

3.1 Introduction

The purpose of this module is to provide the student with background information on pumps regarding start-up and shut-down procedures, operational checks etc.

On completion you should have a general knowledge of these principles. More experience and knowledge will be gained on the plant where you work on the specific types of pumps used.

3.2 Driving force and power

A pump may be defined as a mechanical device for the transfer of liquid. The prime mover may be human hand, diesel engine, electric motor or even a steam engine.

All pumps have three common characteristics, namely:

- a prime mover
- an inlet (also called suction side) and
- a delivery side

This is illustrated in **Figure 3.1** on the following page.

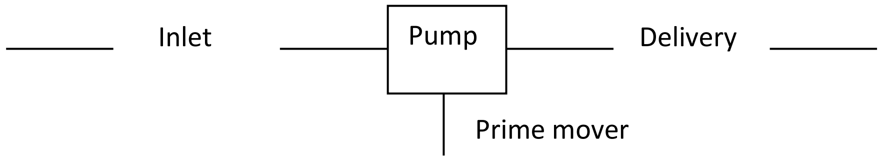


Figure 3.1 Pump characteristics

Pumps are generally designed for a specific purpose; i.e. a pump is required to move a certain liquid at a certain rate through a certain height and along a given route or rising main. The pump so designed will with perform its task with its motor.

3.3 Pump types and uses

All pumps are machines for the transport and movement of fluid which may be affected in several ways, such as:

- By means of a plunger or piston operating within a cylindrical barrel
- By a rotating vaned wheel such as a centrifugal pump
- By a current of air, such as in air lift pumps
- By an oscillating or rotating blade or a pair of meshing gear wheels working inside a casing as in semi-rotary or rotary pumps

Pumps may be broadly classified into the following groups:

- Roto-dynamic
- positive displacement
- diaphragm air lift
- screw pumps

Others classify pumps into two main groups:

- those having valves
- those without valves

Important:
Piston and plunger pumps require valves and give intermittent flow, whilst centrifugal, rotary and air lift pumps do not require valves and produces a continuous flow of liquid.

A centrifugal pump has a rotating element which imparts energy to the water in an action which is the reverse of that of a reaction turbine.

Displacement pumps include the reciprocating type, in which the piston draws water into a cylinder on one stroke and forces it out on the next, and the rotary type in which two cams or gears mesh together and rotate in opposite directions to force water continuously past them.

Pumps are used for a variety of functions in water systems. Centrifugal pumps are used most commonly for low and high service to lift and transport water.

Reciprocating positive displacement and progressing cavity pumps are used to move sludges, vertical turbine pumps are used for well pumping and pneumatic ejectors are used for small wastewater lift stations.

Air-lift, peristaltic, rotary displacement and turbine pumps are used in special applications.

3.3.1 Positive displacement pumps

As the name implies, these pumps will pump a fixed quantity in a given time period. There are a number of different types of which the following are of important:

- Reciprocating pumps with pistons or plungers
- Screw pumps
- Ram pumps

3.3.2 Reciprocating pumps

Reciprocating pumps have differences in the moving portion inside the cylinder. The moving portion may consist of a bucket, a plunger or a piston.

The simplest type of reciprocating pump is the hand operated well pump which must be primed before it will operate and is limited to suction lifts of about 6 m.

On the down stroke the piston valve opens permitting water to enter the space above the piston.

On the upstroke, the piston valve closes and the water above the piston is lifted to the outlet.

At the same time the check valve opens and water is drawn into the space below the piston. By placing the piston cylinder in the well, even perhaps below the waterline, pumps of this type can develop a high lift.

Reciprocating pumps are used extensively in chemical dosing and as metering pumps since every stroke will deliver the same quantity.

Delivery is not constant and an air vessel on the delivery pipe is essential to even out the flow. Piston pumps may be of the single or double action type.

- **Single acting pumps**

Single-acting pumps are very common and in universal use. Discharge occurs only on alternate piston strokes.

The piston, also called a plunger, moves up and down in a cylinder. The piston is fitted with rings, or leathers, to prevent water from escaping between the piston and the cylinder.

Below, in **Figure 3.2**, a single acting piston pump is illustrated.

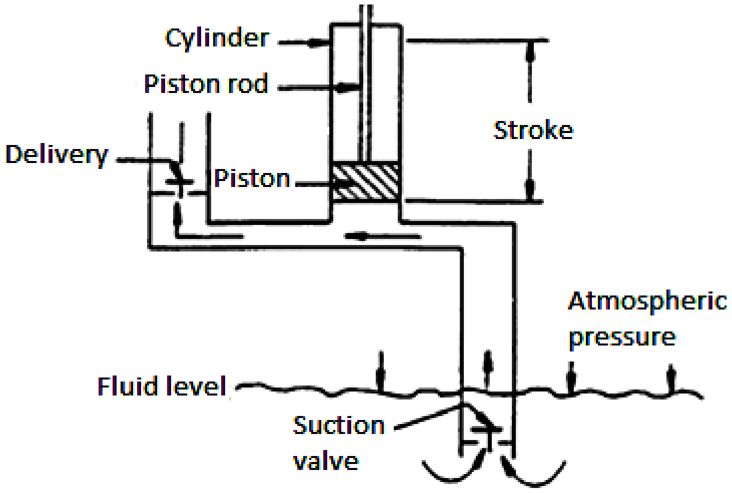


Figure 3.2 Single acting piston pumps

The distance the piston move up and down is called the stroke.

When the piston starts from the bottom of the stroke, and moves upwards, a reduced pressure or vacuum is created in the cylinder and atmospheric pressure on the surface of the water causes the suction valve to lift.

Water then rises in the suction pipe and fills the cylinder. On the down stroke of the piston, the piston pressure on the water exceeds that of atmospheric pressure and closes the suction valve.

The water is now trapped, but with this increased pressure in the cylinder, the delivery valve opens and water is pumped out.

From the above it is now also clear why this type of pump is called a positive displacement pump, because all the water that has been sucked into the pump on the upward stroke is also forced out of the pump on the down stroke of the piston.

If for any reason the delivery side is blocked, mechanical damage will occur e.g. bent piston rod, and burst pipes, etc., as water is not compressible.

⚠	**Important:** A gland and packing is used to prevent leaks where water pressure exists between a stationary and moving part of the pump.

- **Double acting pumps**

These pumps have suction and delivery valves connected to each end of the cylinder, discharges with every stroke and provide a more uniform flow than single acting pumps.

It also operates most satisfactorily against medium pressures. Seen in **Figure 3.3**.

As the piston moves to the right, water is drawn through the left suction valve and delivered through the right delivery valve.

On moving to the left, water is drawn through the right suction valve and delivered through the delivery valve situated on the left side.

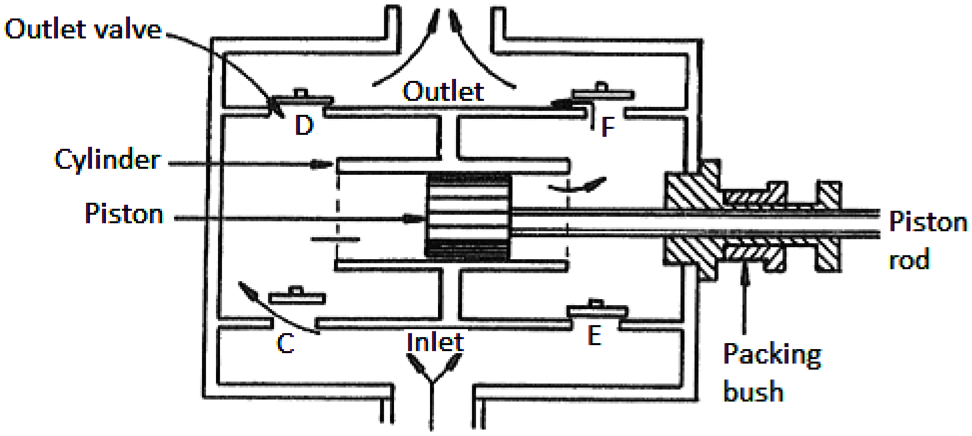


Figure 3.3 Double-acting piston pump

Since a definite volume is discharged with each stroke, the delivery rate of a reciprocating pump depends only on the speed and is independent of head.

The efficiency of a reciprocal pump depends upon the slippage or amount of fluid which leaks between the piston and the cylinder walls during a stroke.

⚠ **Important:**
If the valves and packing are in good condition, slippage should be less than 10 percent of total output.

A reciprocating pump must be primed before it will operate and a supply of liquid for priming is generally provided in the installation.

Before starting, the discharge valve should be opened to prevent high pressures which may damage the discharge pipe or cylinder.

Many reciprocating pumps are provided with an air chamber on the discharge side of the pump. The air in the chamber compresses and expands on each stroke to cause a more uniform flow in the discharge pipe.

Generally these pumps are advantageous only where high-head pumping is required or where their potentially higher efficiency overcomes their high initial and maintenance costs.

- **Principal parts of reciprocating pumps and their function**
  - **Pistons**

To ensure a close fit of the piston to the cylinder, the piston is either packed or else fitted with cup leathers.

- **Pump valves**

Constitute the vital part of any pump and may be grouped into two types: hinged valves and lift valves. Hinged valves often take the form of a flap of leather or canvas.

In the metal hinge type however, the seat joint may be metal-to-metal with the surfaces carefully bedded by scraping, or a pliable material such as leather or rubber may be interposed to give a watertight seal.

> ⚠ **Definition:**
> *Lift valves* are those in which the valve plate remains parallel with the seat as the valves open or close.

The three most common types of lift valves are ball valves, plate or disc valves and ring valves. The valves permit water to pass freely in one direction but prevent backflow.

- **Stuffing boxes**

These are used to prevent liquid in the cylinder from escaping past the piston rod or plunger.

- **Packing**

Rubber is most frequently used for all packing and joints around water pumps. Cotton dipped in tallow is very suitable for the packing of stuffing boxes of externally packed plunger and piston pumps.

Leather is unsuitable for heat and wears quickly in dirty and gritty water. Leather forms a self-tightening packing for pistons, rams, etc. subjected to high pressure.

The leather is placed in a groove of square section. The water pressure inside the ring forces the sides of the leather against the rod and cylinder wall.

- **Strainer**

Prevent rags, dirt, waste sand, etc. from being sucked up by the pump. The total area of the holes should not be less than 3 times the sectional area of the pipe.

- **Foot valve**

This prevents water from flowing out of the pump when out of operation. Hence the pump should not need priming again when restarted.

The foot valve is often fitted with a lever, enabling it to be lifted to drain the pump for repairs.

- **Petcocks**

Allow entrapped air to escape during the priming operation.

- **Priming pipe**

This allows the pump to be primed from an external source when the delivery column is empty.

- **Non-return valve**

This prevents the delivery column from draining itself when the pump stops. It is also vital when repairs are done to the pump and the delivery column has not been drained.

- **Pressure gauge**

It indicates pressure and will therefore immediately show if any blockages, breakage or encrustations occurs in the pipeline. It is illustrated in **Figure 3.4**.

Figure 3.4 Water pump pressure gauge

- **Heads of pump**
  - **Suction head**

By suction head or head is meant the vacuum created by the pump in order to draw water into the suction side of the pump. This is shown in **Figure 3.5**.

The water is raised by means of the atmospheric pressure, which varies with altitude and weather conditions as shown by the barometer.

When the plunger of the pump has completed a suction stroke, a vacuum is formed which tends to suck water up in the suction pipe.

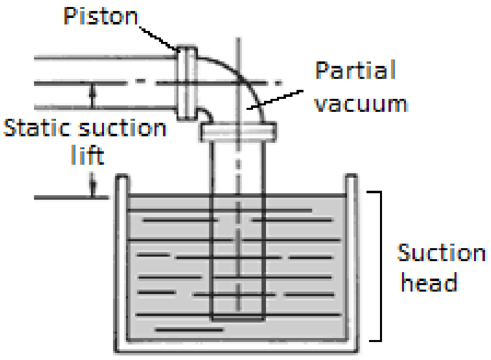


Figure 3.5 Explanation of suction head

– **Flooded suction**

Trouble in the operation of a piston or plunger pump is more likely to occur from conditions arising on the suction side than from any other cause.

This can be eliminated by arranging the water to flow down into the pump suction that is by providing a "flooded suction", as seen in **Figure 3.6** below.

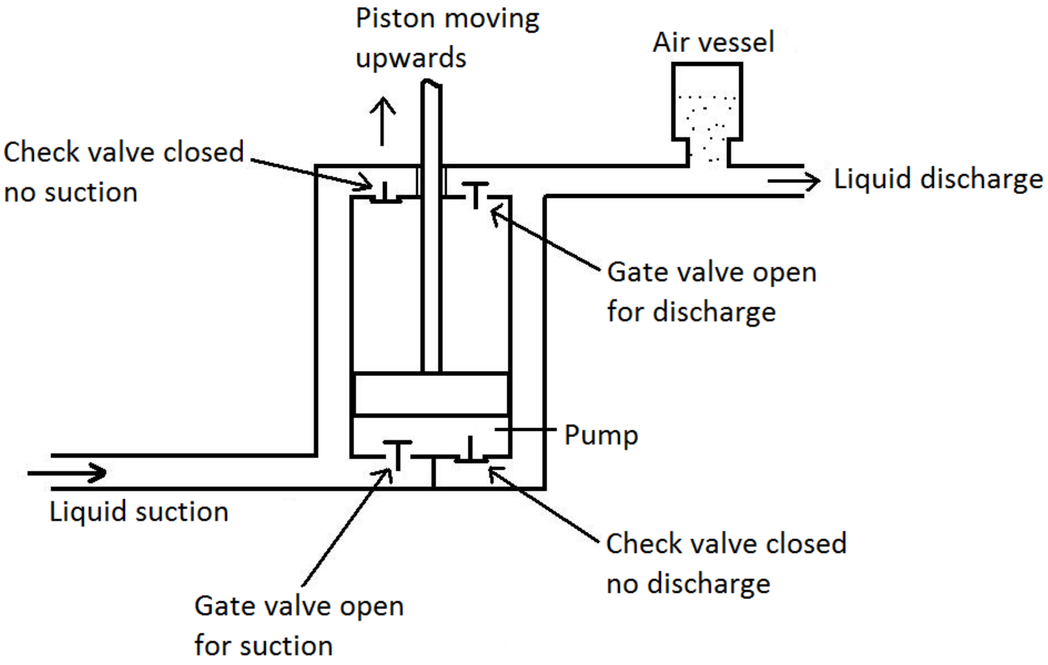


Figure 3.6 Arrangement showing flooded suction

– **Static head of pump**

This is the vertical height measured from the water surface to the point where the water is flowing out of the delivery pipe. The static head is seen in **Figure 3.7**.

Static head = suction head - delivery head.

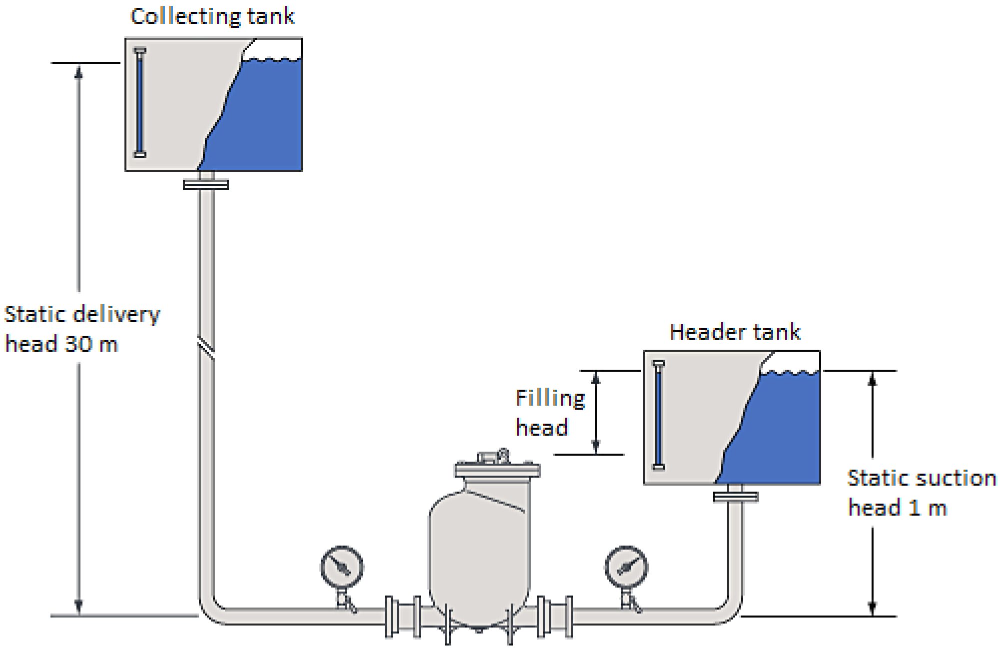


Figure 3.7 Static head

– **Friction head**

When a fluid flows through a pipe, certain resistances which oppose the motion are set up and it is convenient to speak of this resistance as the friction head pumped against.

– **Velocity head**

Work is required to move fluid in a pipe at a certain speed. This work is generally expressed as the velocity head against which the pump must work.

– **Manometric head (or total head)**

This is the head against which the pump must work.

It is the sum of the following:

- Static head (delivery)
- Static head (suction)
- Friction head (due to pipes and fittings)
- Velocity head (due to final velocity of water leaving the delivery column). This is usually so small that it is neglected in calculations.

- Velocity suction head (which is due to the head required to cause water to flow in the suction pipe). It is also neglected unless the pump is working against a very low head.

Manometric head = static head + friction head in suction pipe + friction head in delivery pipe + velocity heads in suction and delivery pipes.

- **Reasons why pump will not deliver very hot water when supply tank is below the pump**

It is essential to create a partial vacuum in the pump when pumping from a lower level. The hot water begins to vaporise and the pump cannot deliver vapour, as the vapour destroys the vacuum.

If there is no vacuum there can also be no suction.

The supply tank should therefore be above the tank when handling very hot water, i.e. a flooded suction is provided.

- **Waterhammer on piston and plunger pumps**

When a liquid flowing in a pipeline is abruptly stopped by the closing of the valve, kinetic energy is converted to pressure energy and a series of positive and negative pressure waves travel back and forth in the pipe until they are damped out by friction.

It may also be caused by a sudden acceleration from rest.

Definition:
Water hammer: A knocking noise in a water pipe that occurs when a tap is turned off briskly.

This phenomenon is known as water hammer. At the instant the valve is closed, water upstream of the valve will be compressed by water flowing against it. This results in a pressure rise which causes a portion of pipe surrounding the element to stretch.

In the next instant the forward motion of the element is stopped, and it, too is compressed by the remaining water in the pipe, which still possess forward motion.

The process is repeated on successive elements until in a relatively short time the pressure wave has travelled back to the reservoir and all the water in the pipe is at rest.

A pressure in excess of hydrostatic cannot be maintained at the junction of pipe and reservoir and the pressure at the reservoir drops to normal as some of the water in the pipe flows back into the reservoir.

Water hammer pressure in general can be greatly reduced by using slow-closing valves, automatic relief valves, air chambers and surge tanks.

If the velocity of flow is increased suddenly by the opening of a valve or starting of a pump, a situation opposite of water hammer develops.

When the valve is opened, an expansion of the water upstream of the valve occurs and a wave of rarefaction travels up the pipe.

⚠	**Definition:** *Rarefaction*: A decrease in the density of something; "a sound wave causes periodic rarefactions in its medium".

While this problem is similar to that of positive water hammer, friction cannot be neglected because of its effect in retarding the development of flow in the pipe.

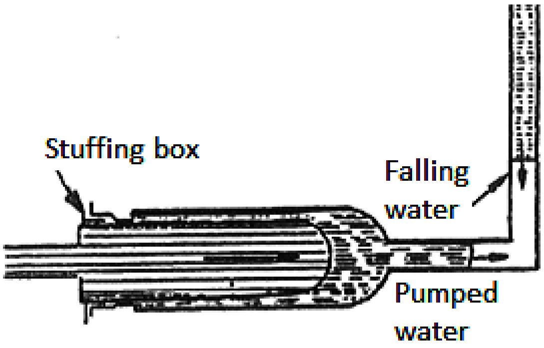


Figure 3.8 Explanation of water hammer

- **How water hammer is neutralised**

Referring to **Figure 3.9**, it will be noticed that during the delivery stroke of the pump, the water in the air vessel is pushed up, compressing the entrapped air.

On the suction stroke the non-return valve closes and the air compression continues to push the water up in the delivery column, with consequently little interruption in the flow of water.

The air vessel therefore:

- reduces the effects of water hammer
- smoothes out the flow of water in the delivery pipes

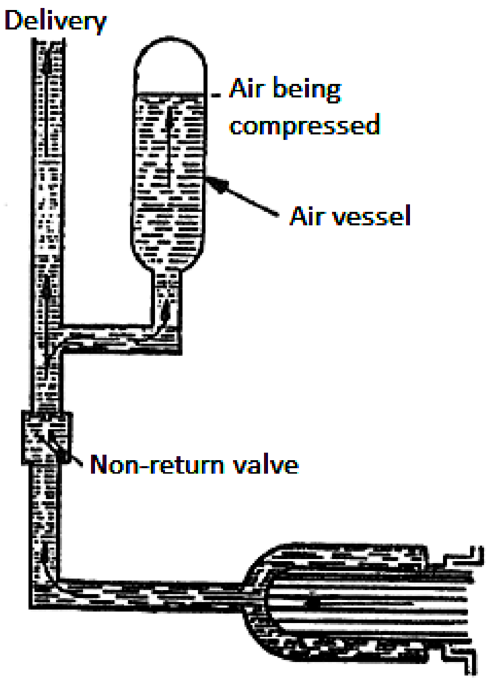


Figure 3.9 Neutralising water hammer

Starting of reciprocating pumps

- Prime the pump by flooding the pistons and valve chambers with water.
- Ensure that discharge valve is closed.
- Open the suction valve and by-pass valve (between suction and delivery).
- Start the pump motor and allow the pump to settle down and run quietly.
- Open the discharge valve slightly and check the bypass valve. Allow to run for some minutes.
- Check for air in the valve chambers.
- Ensure that discharge valve is closed.
- Open the suction valve and by-pass valve (between suction and delivery)
- Start the pump motor and allow the pump to settle down and run quietly.
- Open the discharge valve slightly and check the bypass valve. Allow to run for some minutes.
- Check for air in the valve chambers.
- Watch the ammeter while opening the discharge valve slowly. Close the by-pass valve slowly, checking that the motor is not overloaded.
- After the delivery column is completely charged, the discharge valve should be completely open and the by-pass should be closed completely.

- **Problems experienced with plunger pumps**

Slip is the leakage of water in a pump due to several reasons:

- If the strainer is not completely submerged under water, then air can slip in with the water into the suction pipe, leading to a condition where the pump is pumping both air and water.

- If the foot valve is not efficient, water will slip back into the sump on the delivery stroke, leading to a loss of efficiency.
- If any joint or flanges are loose on the suction column, air will slip in again with the water, resulting in inefficient operation.
- If the suction valves do not open and close promptly and completely (eg due to bad seating, poor springs or grit in the valves) water will slip back into the sump on the delivery stroke.

If the internal packing is not good, water will slip into the right chamber when the plunger is travelling to the left and vice- versa, leading to inefficient operation.

If the external packing is not good, water will slip out of the delivery stroke and air will slip in on the suction stroke.

Pump that refuses to deliver water
The failure of a reciprocating pump to deliver water may be due to the following reasons:

- Pump is not properly primed
- Suction head is too high
- Various mechanical faults
- Air leakages
- Clogged strainer or strainer not deep enough under the water
- Delivery valve or foot valve may be damaged
- Water may be too hot
- Excessive air in water (suction pipe may be too close to a wall-air bubbles)

3.3.3 Archimedean screw pumps

Screw pumps comprise an Archimedean screw supported on a bottom bearing which is submerged in the liquid to be pumped, and by a bearing, gearbox and drive motor situated at the top end.

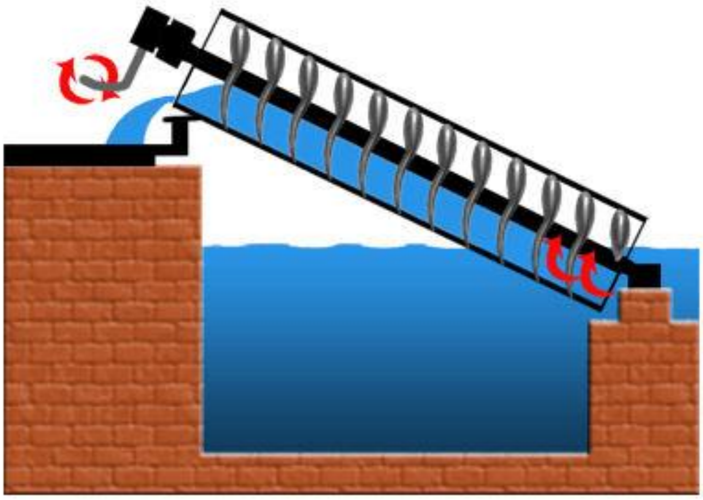


Figure 3.10 Archimedean screw pump

Definition:
Archimedean screw: A device invented by Archimedes for raising water by means of a spiral within a tube. This is seen in **Figure 3.10**.

In these pumps a helical screw revolves in a chamber also of a helical shape.

The screw is inclined at an angle of 25° to 30° to the horizontal. There are no valves in the pump, which is an advantage.

The output of the pump is constant at any speed of rotation, thus the output can readily be varied over a wide range by varying the pump speed. A disadvantage is that the lift is limited by the length of the screw.

This pumping principle was discovered by Archimedes and is applied in almost the original form to transport liquids or suspensions.

A modern version for boreholes has been developed, where the screw is enclosed in a rubber lined cylinder. This type of pump (also called mono pump) can either be positioned horizontally or vertically, seen in **Figure 3.11**.

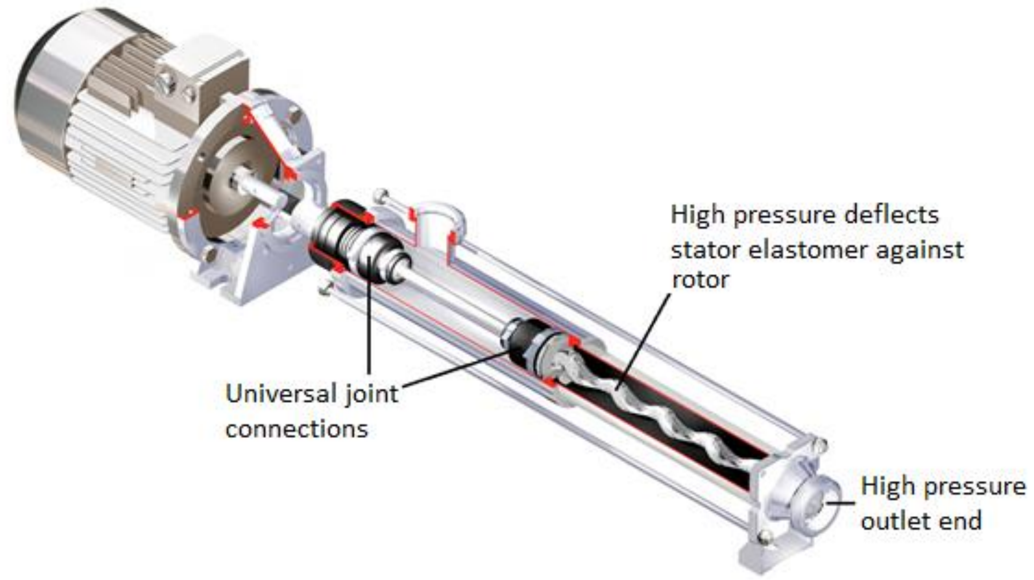


Figure 3.11 Mono pump

These units require virtually no maintenance.

3.3.4 The hydraulic ram pump

A ram pump lifts water by utilising the impulse developed when a moving mass of water is suddenly stopped.

A relatively large amount of water must be available at moderate head to lift a small volume to a high head.

A supply pipe conveys water from the source to the valve box of the hydraulic ram. The valve box contains two automatic valves, a waste valve opening downward and a delivery valve opening upward.

Above the delivery valve there is an air chamber to the base of which the delivery pipe is attached, a steady flow of water occurs through the waste valve with the delivery valve closed.

If the waste valve is suddenly closed, water hammer pressures will develop, forcing the delivery valve open and permitting some water to pass up the delivery pipe.

When the wave of negative pressure returns from the reservoir, the deli very valve closes automatically and the waste valve opens.

A gradually accelerating flow through the waste valve occurs until the net force exerted upward on the valve exceeds the weight of the valve and it closes automatically to begin a new cycle.

The air chamber serves the same purpose as it does on a reciprocating pump, i.e. it reduces the fluctuations in flow through the delivery pipe.

A ram pump, seen in **Figure 3.12**, needs no energy other than a head of water, can be used to lift water from a dam to a supply tank or for other purposes.

The hydraulic ram is wasteful of water, but it may be advantageously employed in situations where no outside source of power is available.

The ratio of wasted water to pumped water for a well-designed hydraulic ram will vary from 6:1 to 2:1 depending upon the supply head, the lift and other factors.

In cases where a portion of the water is required at an elevation below the ram, there may be no waste at all.

The quantity of water pumped depends on the available head and supply, the delivery height, the impulse rate and other factors such as friction, size of pipe, etc. Ram pumps operate continuously and require very little attention.

One objection to this pump is that it produces a considerable amount of noise. Some rams are designed to lift water from a source other than the one which provides water for the supply pipe.

The two waters can be kept separate so that pure water may be lifted with energy obtained from polluted water without any contamination of pure water.

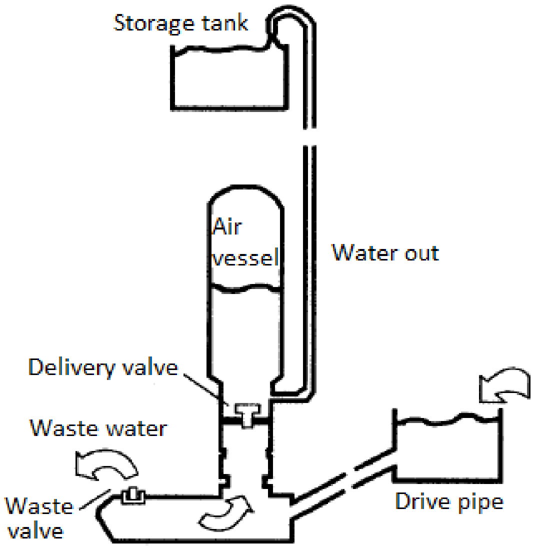


Figure 3.12 Diagrammatic representation of the ram pump

- **Principle of operation**
  - The water commences flow down the pipe from the reservoir into the hydraulic ram.
  - The waste water valve is open and the Water flows through it to waste.
  - As the speed of the water in the reservoir pipe increases, the dynamic pressure on the waste water valve increase, until it is greater than the mass of the waste valve lid. The waste valve will then suddenly close.
  - The closing of the waste valve suddenly brings to rest the reservoir pipe, causing a pressure increase in chamber B.
  - The increase in pressure lifts valve C and some of the water will flow into air vessel D, compressing the air in the vessel.
  - This increased pressure forces the water into the delivery tank.
  - When the momentum of the water in chamber B is destroyed, valve C closes and waste water valve A opens, causing the flow from the reservoir pipe to start the cycle again.

3.3.5 Rotodynamic pumps

Rotodynamic pumps may be classified as:

- centrifugal
- axial flow or propeller pumps
- mixed flow pumps

- **Construction and operation of a centrifugal pump**

An open or closed impeller rotates at high speed in a pump casing as in **Figure 3.13**. The casing is initially filled with the liquid to be pumped (primed) and on setting the pump in motion, the liquid is caught up in the blades.

Due to centrifugal force, the liquid is continuously kept moving from the centre to the outer circumference.

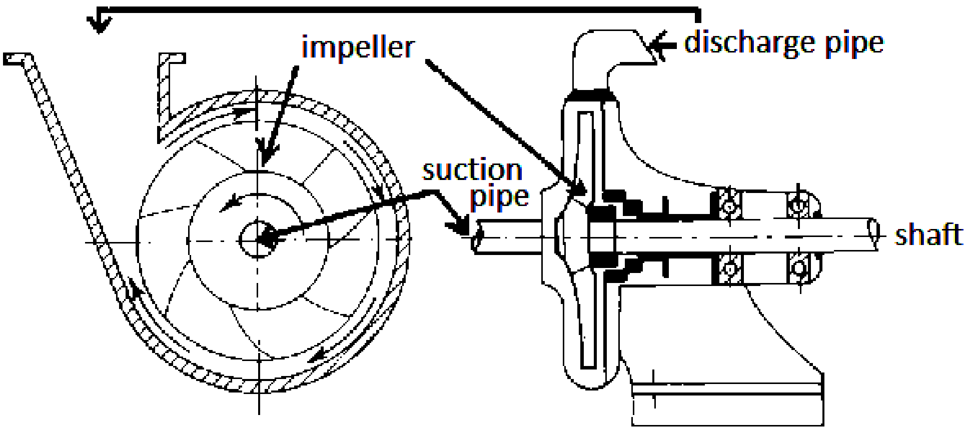


Figure 3.13 Cut through centrifugal pump

Liquid is thus delivered from the suction pipe into the delivery pipe while further liquid is drawn into the suction so that the pump delivers continuously.

When large quantities of liquid have to be delivered against low heads, the pump is fitted with impellers of relatively small diameter but greater lift to provide larger passages for the liquid.

Small quantities pumped against high heads require larger diameter impellers.

Over long distances and high head, a turbine type of pump will be recommended.

Also ensure that gland packings are sealing properly, gland supply water at high enough pressure to prevent sliming of gland.

Other factors include:

- no obstruction on the suction side that may cause cavitations
- damage free delivery pipe
- adequate sized delivery pipe so that friction head is not too high

⚠ **Important:**
Most important is the fact that the pumps must be designed to handle the high head.

For efficient operation of a centrifugal pump the following is essential:

- The pump must be properly primed
- The foot valve may not leak
- The gland packing may not leak excessively
- The shaft must turn at the correct speed
- The impeller must rotate in the correct direction

If the delivery side is obstructed, the impeller will not be able to force water out at its rim and no water will enter the centre of the impeller. As the impeller rotates in the housing, it will continue to rotate without damage to the pump.

With a closed valve, there is no pumping action, thus reducing the load on the prime mover.

Once the prime mover is operating at the correct speed, the delivery valve is opened slowly.

Before starting-up ensure that the suction valve is fully open. If not, a vacuum will be created in the impeller casing, causing overheating of the driveshaft, resulting in damage to the gland packing or seal and suction will be lost.

Centrifugal pumps are used for many purposes, such as high efficiency pumping of clean liquids, the pumping of liquids containing grit or other abrasive material, the pumping of sewage containing solid matter or sewage sludge.

Main advantages of centrifugal pumps:

- Very small floor space
- Low initial costs
- Low maintenance costs, as all motion is rotary
- No sensitive parts such as moving valves
- High speeds of working enabling direct coupling to high speed prime movers
- Small and light foundations
- Capable of handling muddy and dirty liquids, corrosive fluids, hot water up to 400 °C and circulating oil at high temperatures, provided it reaches the pump at high pressure
- Motors are small
- Little if any vibration
- Discharge of liquid is continuous and without shock
- No air vessels or alleviators required
- Flow can be controlled automatically from full flow to no flow without shutting down the pump or damage to the pump or pipes.

- **Cavitation in centrifugal and axial-flow pumps**

Like turbines, centrifugal and axial-flow pumps are subjected to cavitation. It is most likely to occur near the point of discharge from radial and mixed-flow impellers and near the blade tips of axial-flow impellers.

Definition:
Cavitation: The formation of bubbles in a liquid, typically by the movement of a propeller through it.

Cavitation places a limit on the head against which a pump can operate satisfactorily. The limiting head depends on the specific speed of the pump and the suction lift.

Axial flow pumps are more vulnerable to cavitation than other pumps because of their high speed and are therefore restricted to fairly low heads.

When cavitation occurs, bubbles form in the liquid, containing vapour of the liquid together with any dissolved gases which may be released when the pressure drops. The bubbles are of the same nature as those when a liquid boils.

When these bubbles so formed are carried to regions where the pressure exceeds the vapour pressure, they collapse with extreme rapidity and if in contact with enclosing walls, the liquid rushing in to fill the spaces has a water hammer effect.

A repetition of such hammer blows may damage or even destroy the metal.
Metal subject to cavitation first develops a highly polished appearance and then severe pitting may take place.

Apart from this, repeated collapsing of the bubbles may set up dangerous vibrations.

Any centrifugal pump has, when operating under its designed conditions, a net positive suction head. This is the head required to force the water into the pump without cavitation occurring.

Eddying produce areas of low pressure and careful design of the suction side, e.g. avoiding sudden changes in direction and making the vane inlet tips of aerofoil section, will reduce the required suction head.

In the case of a badly designed pump, or a pump running at excessive speed, head may exceed atmospheric pressure.

In other words, cavitation may occur even with flooded suction.

To prevent cavitation:

- atmospheric pressure must exceed the net positive suction head
- a flooded suction should be provided or if this is impossible, the suction lift should be as small as possible
- suction pipe should be as short as possible and of ample diameter
- as one cause of cavitation is the release of dissolved gases, the suction pipe must rise continuously toward the pump and all pockets in which released gases may collect, must be avoided
- minimise friction and velocity losses in the suction pipe

  - eliminate turbulence as far as possible
  - prevent air from entering suction

- **Causes of centrifugal pumps failing to deliver**
  - pump not properly primed
  - suction head too large
  - air leakages at inlet pipes and packed stuffing boxes
  - strainer blocked and liquid cannot flow to pump casing
  - pump speed too low for pressure build-up
  - pump may be badly worn or some other mechanical fault
  - strainer not properly submerged under water thus permitting air to be drawn in with water

- **Starting up procedures of different types of pumps**
  - **Pump with volute casing**

Employed to pump large quantities of liquid against comparatively low heads and is used for pumping sandy or gritty water.

  - **Turbine type of centrifugal pump**

This is used to pump medium quantities of clean water against comparatively high heads.

- **Starting up procedure**
  - Open all petcocks
  - Connect priming pipe with external water supply and open valves
  - Turn pump slowly as the water runs into the casing to release air pockets
  - Close all petcocks
  - Open main delivery valve
  - Throw in switch
  - Cut out the electrical resistances as the pump build up speed
  - Watch the pressure gauge and ammeter

3.3.6 Air lift pumps

An air-lift pump consists of a tube immersed in the liquid to be pumped and uses compressed air to deliver water from wells, seen in **Figure 3.14**.

The pressure of the air supply requires being only slightly in excess of that necessary to blow the air down to the submergence of the air pipe, i.e. a little less than 10 kPa per metre submergence.

The air is forced through a small air pipe and discharged into the eduction pipe at the bottom of the well.

Definition:
Eduction pipe: The pipe by which the steam from the cylinder is led into the condenser or allowed to escape into the atmosphere.

The resulting mixture of air and water in the eduction pipe is lighter and less dense than the water outside the pipe and hence is forced upward by hydrostatic pressure.

This type of pump has been used for lifts as great as 150 m but its efficiency is usually only between 25 and 50%.

In spite of low efficiency an air lift can deliver large amounts of water from small diameter wells. The air lift is not harmed by sandy water and is particularly suitable for use in crooked or damaged wells.

A separator is often placed at the discharge end of the eduction pipe to remove the air from the water.

The reclaimed air is usually cooler than atmospheric air and can be recompressed more cheaply. An air-lift pump is not adapted to raising water much above ground-level and if this is necessary, a second pump may be required.

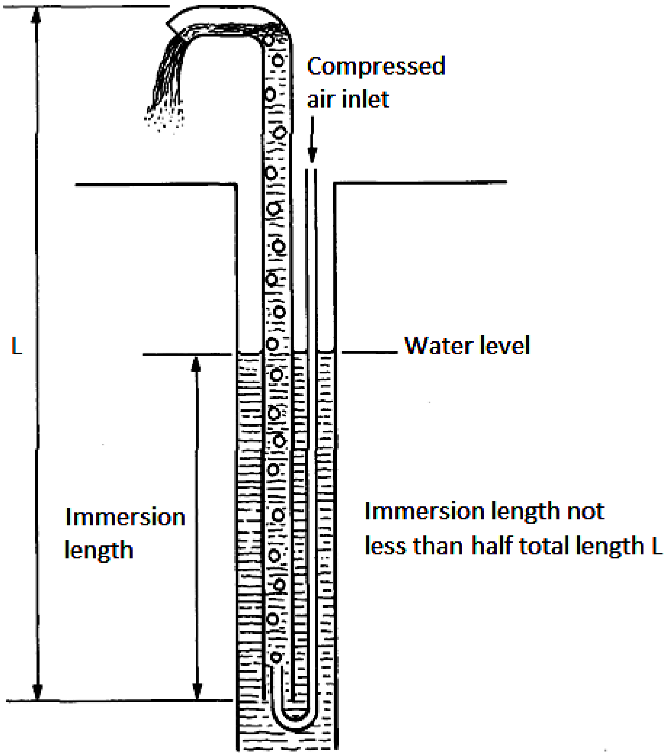


Figure 3.14 Schematic diagram of an air-lift pump

As the upward velocity is efficient to lift solid matter such as grit and stones, it is very useful in emptying detritus pits or sludge tanks as such matter passing through other types of pumps would cause excessive abrasive wear and blockage.

Air-lift pumps have no moving parts and require only a supply of compressed air for their operation. They require less space than any other type of pump and are the least liable to choke. However, the air compressor requires regular maintenance.

3.4 Operation of pumps

3.4.1 Preparation for start-up

To prevent damage and ensure proper operation of the pump, the following checks should be carried out prior to starting:

- sufficient water in sump or dam
- suction valve and petcock open
- strainer box clean
- pump turns freely
- bearings adequately lubricated
- stuffing box not leaking excessively
- coupling guard in position
- delivery valve closed
- pump fully primed

3.4.2 Starting

Starting procedure will vary depending on the pump application and the type of drive used with the pumps.

When manually starting a rotodynamic pump after it has been primed, leave the discharge valve closed until the pump has run up to speed, i.e. when the pressure gauge indicates it's known no-load pressure. Then gradually open the discharge valve.

When operating with flooded suction, or with self- priming pumps, automatic operation can take place once the rising main has been filled. Then the discharge valves may be left open as well.

On positive displacement pumps, it is imperative that the discharge valve be left open at all times.

On self-priming pumps the discharge valves should, at least, be cracked to allow for the venting of the air in the suction main. On regenerative type of pumps where increasing flow means decreasing power consumption, the discharge valve should remain open.

The following is a general starting-up procedure:

- Close petcock
- Start the pump
- Open delivery valve slowly

- Observe ammeter reading
- Check that the bearings are not overheating
- Check that stuffing box is not overheating
- Check reading on pressure gauge if fitted. If not, open pet cock and check that water is forced out under pressure

3.4.3 Operating checks

In order that the pump is operating properly, it should be checked when first started and periodically thereafter to prevent minor problems becoming major repair jobs.

The following are examples of operating checks:

- Check for any unusual noises or excessive vibration
- Check all pump connections for evidence of leaking
- Check the pump for overheating
- Check the suction strainer and clean if necessary
- Be especially alert for unusual sounds when pumping liquids containing solids

3.4.4 Stopping

Reduce the pump speed (if possible), close the discharge valve slowly and stop the pump.

In below-freezing conditions, remove the volute drain plug and drain the pump to avoid damage to the wear plate or wear ring from freezing.

If the pump has been pumping corrosive liquids or liquids containing a considerable amount of solids, open the drain plug and drain and flush out the pump thoroughly with clean water.

3.5 Selection of pumps

The centrifugal pump is most commonly used for ordinary pumping as it provides satisfactory and economic service.

At very low flow rates the rotary pump may be just as satisfactory and less costly if the water to be pumped is free of grit.

The discharge of a centrifugal pump varies with the head, and a variable-speed drive is necessary if constant discharge is to be maintained under varying head.

A reciprocating pump overcomes this difficulty since its discharge depends only on the speed of the pump. Reciprocating pumps are high in initial cost and difficult to maintain in efficient operating condition.

They are best adapted for use under very high heads. Centrifugal pumps are well suited to pumping wastewater and water containing solids, but displacement pumps are not generally used for such duty.

The hydraulic ram, although wasteful of water, finds occasional use where water is plentiful and outside power unavailable.

Important:
The type of well pump selected depends on the depth of the well and the desired flow.

A hand-operated reciprocating pump is satisfactory for shallow wells if only a small and intermittent discharge is desired.

For deeper wells, a deep-well turbine pump or deep well reciprocating pump may be used. The air-lift or jet pump is suitable for wells where the discharge is not large.

Jet pumps are also used for dewatering excavations, although self-priming centrifugal pumps are more commonly used for this purpose.

Activity 3.1

1. Name three groups of rotodynamic pumps.
2. For which purposes will you recommend centrifugal pumps?
3. Name the advantages of Archimedean screw pumps.
4. Name four causes why a centrifugal pump fails to deliver liquid.
5. Describe water hammer and how you would neutralise it.
6. When a pump is running at its design speed, name one cause for each of the following:
   a) insufficient liquid delivery
   b) vibration
7. Which operating checks should be carried out regularly on pumps to prevent major breakdowns?

Self-Check

I am able to:	Yes	No
• Describe driving force and power		
• Describe pump types and uses		
o Positive displacement pumps - reciprocating, Archimedean screw, ram pumps		
o Water hammer, starting and slip		
o Rotodynamic pumps, air lift pumps		

- Explain the operation and maintenance of pumps and motors		
- Describe the selection of pumps		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 4

Valves

Learning Outcomes
On completion of this module, students should be able to:

- Explain what a valve is
- Describe the types of valves
- Explain valve operation, maintenance, safety operations and precautions
- Describe cavitation and the prevention thereof
- Explain corrosion and the prevention thereof
- Explain how to keep records

4.1 Introduction

This module serves partly as refreshment of memory regarding valves discussed previously in N1 and N2. There are, however, some new concepts included. Once completed, you should have a good background knowledge regarding valves.

4.2 What is a valve?

In order to understand the operation, application and maintenance of valves, it might be well if the definition of a valve is considered.

For the purpose of this discussion, a valve is a mechanical device usually used in connection with a pressure-containing vessel to completely stop or regulate flow.

As a mechanical device, a valve should be selected to do the job expected of it and should be properly installed. It will then give long service before it starts to leak or wear out.

After installation and periodically during service, a valve should be checked to ensure that it has the necessary seal tightness.

4.3 Types of valves

Valves are installed throughout water systems in treatment plants, pumping stations and pipe networks, as well as at storage reservoirs. Their purpose is to control the magnitude or direction of water flow.

In order to regulate flow, all valves have a movable part that extends into the pipeline for opening or closing the interior passage.

The four basic kinds of valves are:

- Slide
- Rotary
- Globe
- Swing

Others less common are:

- Sphere
- Diaphragm
- Sleeve
- vertical-lift disc

Valves are also commonly classified by operating purpose (shut off and altitude) and function (by-pass and flow control) without regard to the kind of device used.

When valves are classified according to closing mechanism, there are mainly three types:

1. Gate valves (sluice valves)
    - with non-rising shaft
    - internal screw with rising shaft
    - external screw with rising shaft
2. Ping valves (check valves)
3. Globe valves

There are also valves for special purposes:

- Needle valves
- Diaphragm valves
- Check valves
- Safety valves and release valves

4.4 Operation, maintenance, safety regulations and precautions

The means of operating the movable element of a valve are by screw, gears or water pressure.

Screw stems are common in gate, globe and needle valves that can be opened or closed by a manually operated hand wheel or by a powered operator.

In some designs the screw stem rises as the shut-off element closes and in others the element rides up the screw inside the body of the valve as the stem turns; the latter non-rising stem is more common.

Water pressure can open or close some kinds of valves by direct pressure on the movable element. The simplest is a hinged swing gate that opens under water pressure and close under the influence of gravity or back pressure.

Regardless of the manner in which the valve is manipulated, care should be taken not to exert too much force on the closing mechanism, thereby damaging the valve.

When pumping warm liquids, the valve should be turned on a few minutes after closure to ensure that it is properly closed.

The liquid and valve will cool down when flow ceased, causing the parts of the valve to shrink and possibly allow liquid to flow through.

The various designs of valves are developed from one idea - to place a disk over a seat opening in such a way that the resulting closure is tight.

This one idea branches out into several basic designs of valves, including globe, check, gate, ball and butterfly valves. Each design places the disk over the seat in a different manner.

Valves are usually made of one of three different metals for the following reasons:

- **Bronze** for temperatures up to 288 °C Bronze is corrosion resistant to a large majority of fluids and is easy to cast and machine.
- **Cast iron** for temperatures up to 232 °C. Cast iron is cheaper than bronze.
- **Cast steel** for temperature up to 593 °C. Steel is stronger at high temperatures than bronze or cast iron.

4.4.1 Shut- off valves

Valves to stop the flow through a pipeline are the most abundant valves in a water system.

Pipe networks are sectionalised by installation of shut-off valves so that any area affected by a main break or pipe repair can be isolated with a minimum reduction in service and fire protection.

In treatment plants and pumping stations, shut-off· valves are installed in inlet, outlet and by-pass lines so that valves and pumps can be removed for maintenance and repair.

Gate valves are popular shut-offs; however rotary butterfly valves may be installed in large diameter pipes.

⚠	**Definition:** *Gate valve*: (also known as a sluice valve) Is a valve that opens by lifting a round or rectangular gate/wedge out of the path of the fluid.

A gate valve consists of a sliding, flat, metal disk that is moved at right angles to the flow direction by a screw-operated stem. When installed in pipeline, the disk is drawn up into the housing, permitting free flow of the water through the valve opening.

The gate is lowered into snugly fitting side channels to block the water flow. The valve is opened or closed by using an extension rod.

Gate valves are by far the most popular and the most frequently used. They are opened and closed only infrequently and last a long time without requiring much maintenance.

Gate valves are used to regulate flow in a pipe and should be installed with the stem vertical if at all possible; otherwise the operation is not as good.

Valve stems should be kept lubricated and free from dirt. Should the downstream seats become scored, the upstream seats would frequently found to be in good condition. Reverse the valve 180° and the valve will be as good as new.

Should it become necessary to replace the seat rings, remove the valve from the line and prepare a pipe of the correct size. Clean all threads and seating surfaces with a wire brush before installing new rings.

A new disk should be installed with new rings. Retighten body bonnet bolts uniformly using a criss-cross pattern and at least three passes.

A butterfly valve, seen in **Figure 4.1**, has a movable disk that rotates on a spindle or axle set in the shell. The circular disk rotates in only one direction from fully closed to fully open and seats against a ring in the casing.

⚠	**Definition:** *Butterfly valve:* A valve consisting of a pair of semicircular plates that are attached to a spindle across a pipe and hinged to allow flow only one way.

The main disadvantages of a butterfly valve results from the disk always being in the flow stream, restricting the use of pipe cleaning tools.

On the other hand advantages of this valve are tight shut-off, low head loss, small space requirement and throttling capabilities.

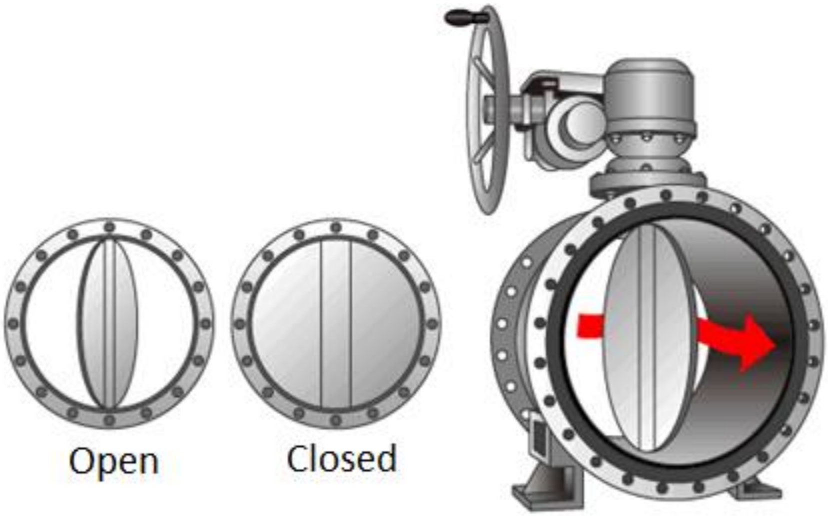


Figure 4.1 Butterfly valve

This type of valve has been used in sizes of 5 cm to 8 m. The small sizes may be used as regulating valves, while the larger ones are used as guard valves.

It is best suited for moderate heads, although they have been used under high heads. Careful design is necessary as severe structural loadings may result from the flowing water.

Butterfly valves are much more easily repaired than conventional valves. It finds application in most categories where valves are used.

Body materials are aluminium, cast and ductile irons and carbon and stainless steel.

The maintenance of these valves is quite simple. No lubrication is necessary until such time as stem o- rings need replacement. Disks, stems, disk o-rings and replaceable resilient seats are easily replaced.

4.4.2 Check valves

A check valve is a semi-automatic device that permits water flow in only one direction. It opens under the influence of pressure and closes automatically when flow ceases.

When backflow takes place which is larger than the flow pressure, the valve closes automatically and backflow is checked.

Usual installations are in the discharge pipes of centrifugal pumps to prevent back-flow when the pump is not operating.

It is also used in conjunction with altitude valves in connections between storage reservoirs and the distribution network.

Definition:
Check valve: A valve that closes to prevent backward flow of liquid.

Check valves are guardians against backflow in a pipeline. They are entirely automatic in action with various designs.

Check valves fall into two general groups, commonly known as “swing check" (e.g. swivel disk non- return valve) and "lift check" (safety and release valves). A swing check valve is usually used where full flow is desired.

A lift-check valve is usually used on air or gases when the operation of the check valve is quite frequent. It is clear that the valve seating should be clean and smooth as foreign material on or unevenness of the seating will encourage backflow.

Maintenance on the disk check valve consists of replacing the disk when necessary, smoothing the upper and lower surfaces when necessary and removing grooves or worn places from the seat with a reseating tool.

Swing-check valves are probably the most popular and most used of all check valves. They can be installed in horizontal or vertical lines with flow.

Maintenance consists of regrinding the disk to its seat by applying a screwdriver to the slot in the top of the disk and using a grinding compound.

If carrier pin, plugs or disk carrier becomes worn, it can be easily and inexpensively replaced with new parts.

Ball check valves are considered the ideal check valve by some people. In the opinion of specialists, it should be used only on viscose or heavy fluids such as muddy water or liquid containing solids.

Any of these would clog the mechanism of other check valves.

There is little maintenance on the ball check valve as there is no means of holding the ball for regrinding the seats. This ball must be as perfect a sphere as possible and the seat perfectly round.

Safety valves and release valves are used with gases and liquids. There is no difference in their design and operation and both protect personnel, equipment, equipment and processes against the risk of excessive pressure that could otherwise cause explosions.

Definition:
Safety valve: A valve opening automatically to relieve excessive pressure, especially in a boiler.

In the case of gases, provision must be made for the expansion thereof to a large volume as a result of the pressure which decrease or is relieved when the gases pass through this opening.

When a gas is under pressure and it is released through a small opening, there is a tremendous force that has to be reckoned with.

In the case of gases, the safety valve is so designed that the slightest pressure above the set pressure immediately opens the valve to let the gas out.

For liquids under pressure it is not necessary or desirable to release a large volume quickly, because there is no tremendous force released as with gases.

The valve is thus designed according to requirements. Water hammer pressures in pipes can be minimised by use of pressure relief valves, seen in **Figure 4.2**, adjusted to open automatically at a predetermined pressure.

This type of valve is used on small pipelines where the escape of a relatively small amount of water will alleviate water hammer pressures. Either a spring or a counterweight may be used to set the opening pressure.

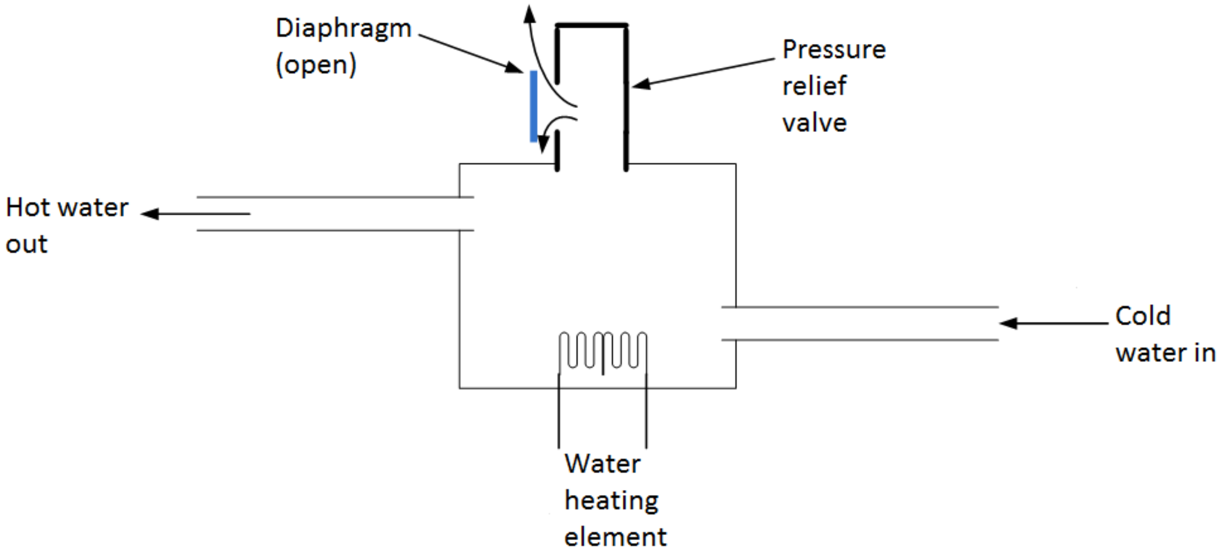


Figure 4.2 Pressure relief valve in the open position

The most general safety valve is the type where the valve is held on the seating via a spiral spring. Regulation of the pressure that will let the valve open is obtained by changing the length of the spiral spring by means of a set screw.

The tighter the spring has been screwed down, the higher the pressure required to open the valve.

Every hydraulic circuit should be fitted with a relief valve to act as a safety valve and to prevent damage due to the pressure becoming too high.

Relief valves are also used to maintain a constant pressure in a hydraulic system by allowing the excess liquid from the pump to escape continuously.

⚠	**Definition:** *Relief valve*: A valve in a container in which pressure can build up (as a steam boiler); it opens automatically when the pressure reaches a dangerous level)

Distribution-system water quality can be adversely affected by improperly constructed or poorly located blow-offs of vacuum or air relief valves.

Relief valves are installed to allow the entrance of air and thus prevent collapse or damage to a line not capable of withstanding atmospheric pressure or when under vacuum.

These valves have no effect on quality except as a preventive measure in reducing the possibility of breaks.

They should be so located and protected, however, as to prevent the entrance of contaminated or polluted water when open.

The maintenance of steel valves consists of periodic checks for shell and seal tightness, periodic lubrication and exercising and repacking when needed.

Repair of steel valves is more difficult than for other valves because of their harder materials, integral lay on or welded- in seat rings, larger size and weight and use of welded pipe connections.

Globe and gate valves must be removed from the line and machine tools used to renew the seats or else special power equipment can be used to renew the seats in line.

An example of a globe valve is seen in **Figure 4.3** on the following page.

⚠	**Definition:** *Globe valve:* A type of valve used for regulating flow in a pipeline, consisting of a movable disk-type element and a stationary ring seat in a generally spherical body.

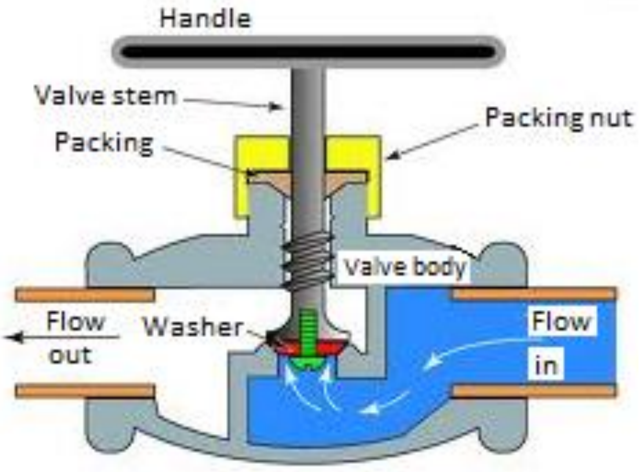


Figure 4.3 Globe valve

Valves with welded-in seat rings must be removed from the line for replacement of seat rings, which is best done by the manufacturer or a valve reconditioning shop.

Gate valve wedges can be hand lapped on a surface plate with lapping compound if their condition is not too bad.

Needle valves are in fact small globe valves with locking mechanisms similar to needles.

The needle penetrates into the valve seating and allows only small quantities of liquid or gas to pass. It is used for fine regulation of especially gases and light liquids.

This is achieved by making the screw thread much finer so that the movement to the shaft is very small and it usually has a fine conical closer so that the upward movement of the closer makes a small difference in the valve opening.

Plug valves, seen in **Figure 4.4** on the following page, can be opened or closed completely and be placed in any position between these two extremes.

The properties of the liquid to be handled and the accuracy of flow that is required, decides the design of the valve while the basic design remains the same.

In the plug valve, the flow direction of the liquid is changed twice through 90° and there is thus a relatively high pressure loss.

Figure 4.4 Plug valve

Plug-type valves (used as isolation valves) are similar in construction and uses as ball valves.

A ball valve, as shown in **Figure 4.5**, has a spherical closure element (or ball) with a port through it mounted on renewable Teflon seats. To open the valve, the ball is rotated so that the through-port lines up with the seat openings.

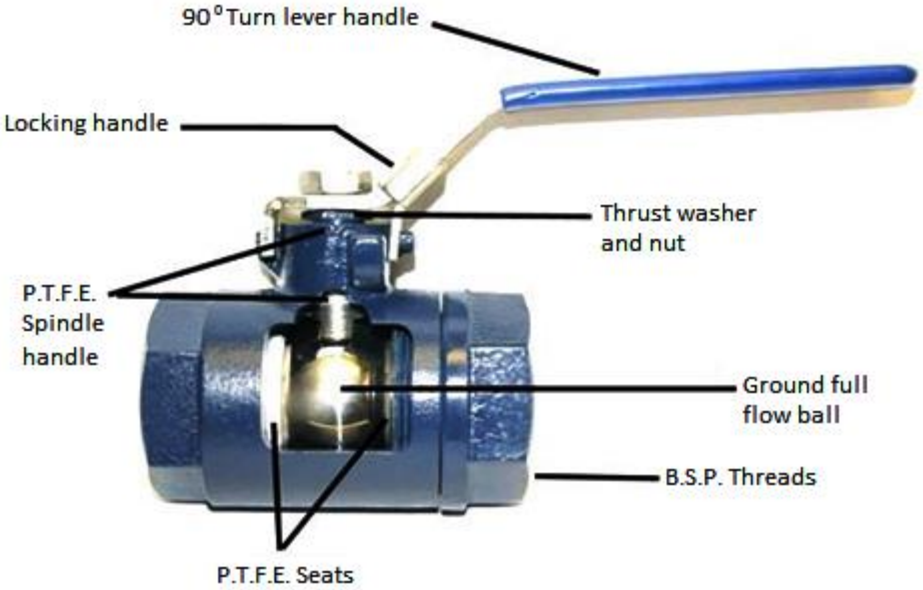


Figure 4.5 Ball valve

When the valve is closed, line pressure forces the ball against the downstream seat in an action similar to that of a gate valve.

The ball valve is more compact, tighter sealing, quicker operating and more easily maintained than conventional gate or globe valves and has better flow characteristics.

It is used in many services where conventional valves would have been used formerly.

4.4.3 Cavitations and the prevention thereof

This was already discussed in **Module 3**.

4.4.4 Corrosion and the prevention thereof

Corrosion is the natural way in which chemical forces act upon metals to return it to their ores. Physical forces allied with chemical forces considerably accelerate the corrosion process.

The following most common types of corrosion can readily occur in valves if the correct design and material selection are not carefully considered from the outset.

Definition:
Corrosion: The process of corroding metal, stone, or other materials and the damage caused by such a process.

- **Uniform chemical attack**

This is a common form of corrosion, particularly with metals which are in contact with acids and other corrosive solutions.

The corrosion product frequently forms a protective layer on the surface of the metal, thereby slowing down corrosion and resulting in a uniform wasting away of the surface.

Where direct chemical attack has taken place, the products of corrosion are readily dissolved in the corrosive medium and accelerated corrosion takes place.

Wherever severe chemical attack has taken place, there would invariably have been a higher grade of material which could have been selected for construction of the valve.

- **Galvanic corrosion**

This occurs when two dissimilar metals are in contact and subsequently exposed to a corrosive liquid.

One method to minimise galvanic corrosion is by plating the dissimilar metals but this all too often suffers the disadvantage of cracking and delaminating.

Care should be taken in selecting a superior alloy which will have considerable corrosion resistant advantages even over that of stainless steel.

- **Intergranular corrosion**

This may be caused through a number of reasons but the results are virtually the same; selective attack along the grain boundaries of the metal, loss of mechanical properties and inter-crystalline cracking.

- **Pitting corrosion**

Once the protective film or corrosion layers break down; localised corrosion known as "pitting" results.

In the presence of highly corrosive media (e.g. chlorine) stainless steel valves have been known to suffer pitting through the presence of so-called "rough spots".

It is again emphasised that noble alloys, considerably superior to that of stainless steel are available and that valve life can be extended by up to five times through the correct selection of materials.

- **Stress corrosion**

When high mechanical stresses are combined with corrosive media, corrosion speeds up at a far greater rate than the sum of the damage that these two factors could cause individually.

Superior valve design coupled with the stress relieving of components during manufacture, together with correct material selection can overcome failure due to stress corrosion.

- **Crevice corrosion**

This is a common cause of localised corrosion in valves which have sharp corners, gasket joints (such as those in 2 or 3 piece valves), areas where accumulations of deposits can build up and stagnant areas.

Once again superior valve design will help eliminate this problem.

4.5 Records

Records are useful for review purposes, for providing the basis for improvements and changes in operation work and maintenance planning, predicting and forecasting, for evidence, for financial purposes and for securing economical results.

Basic documents for a distribution system are:

- maps showing mains, valves, hydrants and service connections
- data for each valve are retained on an additional valve record card

Precise location is described by at least two permanent reference points. Additional data on the cards are valve number, type, size, model and manufacturer, number of turns and direction of turning to open as well as a record of inspection and maintenance of the valves.

Inventories should also be kept on valves and spare parts stocked for installation and repair work.

To make this mass of data usable, it can be summarised and placed on a larger monthly-by-day record sheet for permanent keeping. Furthermore records are only of use if they can be found easily and reliably.

A systematic filing system should be developed for all records to keep them safe and readily available. Recording information in this way will provide you with a life history for each piece of equipment.

Other records to be kept are:

- design parameters (ability of the plant)
- flow records (influent and effluent)
- performance records
- accounting
- temperature
- pH
- weather conditions
- laboratory results, etc.

Activity 4.1

1. Name four types of valves
2. Name three types of corrosion
3. Give two reasons for keeping records

Self-Check

I am able to:	**Yes**	**No**
• Explain what a valve is		
• Describe the types of valves		
• Explain valve operation, maintenance, safety operations and precautions		
• Describe cavitation and the prevention thereof		
• Explain corrosion and the prevention thereof		
• Explain how to keep records		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 5

Elementary Water Chemistry

Learning Outcomes

When you have completed this module, as a learner you will be able to:

- Understand general chemistry
    - elements
    - atoms
    - atomic mass
    - valency
    - compounds
    - mixtures
    - solutions
    - molarity
    - suspensions
    - colloidal
    - suspensions
    - chemical symbols
- Describe gases, their solubility in water and the effect temperature on the equilibrium
    - CO_2
    - O_2
    - H_2S
- Describe organic and inorganic compounds
- Describe cations and anions occurring in natural water
- Describe oxidation and reduction
- Describe dissociation, ionisation
    - H^+
    - OH^-
    - acids and bases
    - pH
- Describe alkalinity and buffer capacity
- Explain the concentration of chemical reagents; mole versus normality
- Describe adsorption
- Understand the periodic table of elements

5.1 Introduction

Chemistry is the branch of science dealing with the composition and properties of different matter, their laws, combination and behaviour under various conditions.

Furthermore it deals with changes in matter, the mechanisms by which these changes occur, the products formed and the energy changes encountered.

5.2 General chemistry

5.2.1 Elements

It is also not possible to simplify elements further by the usual methods used to cause chemical changes, which include application of heat, light or electric energy. Elements are the basic building blocks of all chemical compounds.

Definition:
Element: A specific type of matter consisting of only one type of atom. It is the smallest part of a pure chemical substance which cannot be further decomposed by ordinary chemical action into a simpler substance.

To each element is assigned a symbol representing atoms of the particular kind.

The symbol consists of one or two letters derived from the English or Latin name of the element.

5.2.2 Atoms

It is the difference between atoms of different elements that cause the difference between elements.

Definition:
Atom: An atom is the smallest part of an element able to exist alone or in combination with other atoms of the same or different kinds and still have the characteristics of the element.

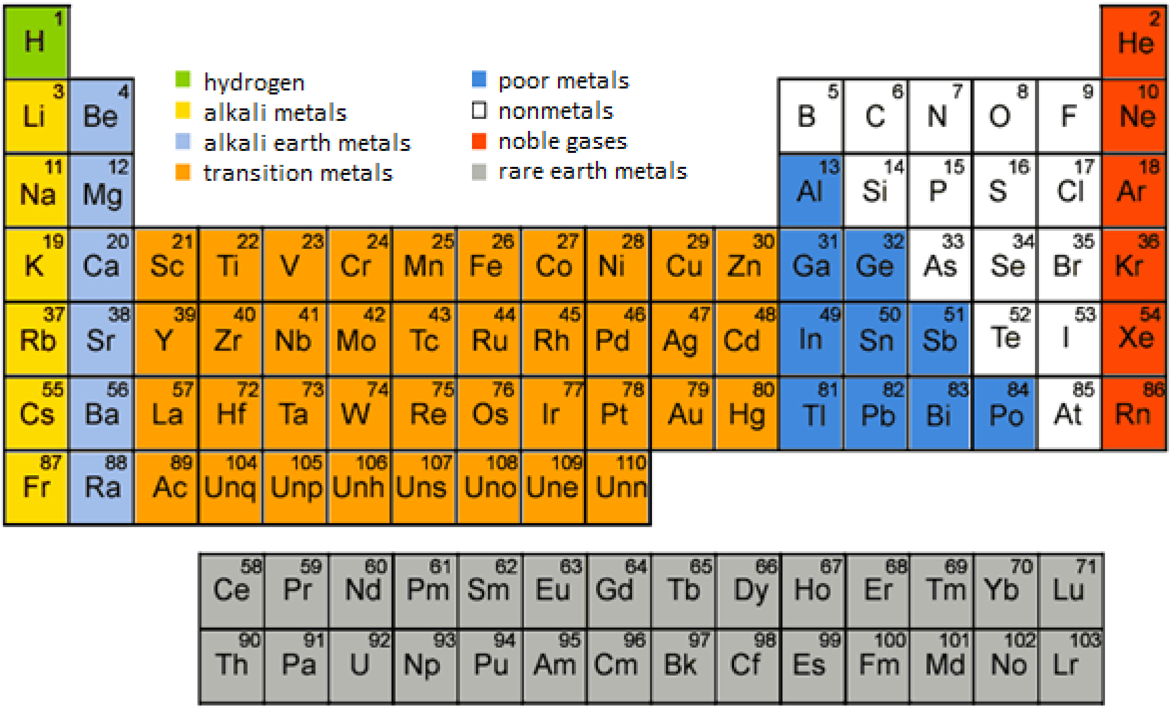
Atoms consist of two main parts:

- the positively charged central part called the nucleus (consisting of protons and neutrons) and
- the electrons which are negatively charged, around the nucleus

5.2.3 Atomic mass

The mass number of an atom is the sum of the number of protons and neutrons in the nucleus. The mass is obtainable from the Periodic Table of Elements in

Figure 5.1 but can also be calculated; e.g. Al is element number 13, with 13 protons and 14 neutrons and an atomic mass of 27.



1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Unq	105 Unp	106 Unh	107 Uns	108 Uno	109 Une	110 Unn								

58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Figure 5.1 Periodic Table of Elements

5.2.4 Valency

Atoms of one element unit with another in a definite ratio defined by their valence. Valence is the combining power of an element based on that of the hydrogen atom which has an assigned value of 1.

Definition:
Valency: The valency number of an atom is the number of electrons too many or too few in the outermost energy level to form the structure of a noble gas.

Thus an element with a valence of 2^+ can replace two H atoms. Sodium has a valency of 1, therefore one atom of sodium will combine with one chloride atom to form sodium chloride.

Nitrogen at a valency of 3^- will combine with 3 H atoms to form ammonia gas (NH_3).

5.2.5 Compounds

Compounds consist of two or more elements combined in a definite ratio, with definite composition. The formula of the chemical compound represents, by appropriate subscripts, the relative number of each constituent element present in the compound.

Definition:
Compound: A compound is a substance which may be decomposed into two or more simpler substances by ordinary chemical means.

5.2.6 Mixtures

A mixture is a material consisting of two or more kinds of matter, each keeping its own characteristic properties. They do not combine chemically with each other, e.g. air of which the main component is oxygen and nitrogen.

5.2.7 Solutions

Solutions can filter unchanged through the finest filter paper. Solutions can be dilute, containing a small amount of dissolved solids or concentrated containing much dissolved matter.

Solubility increases with an increase in temperature. Gases however are more soluble in cold water than in hot water.

Definition:
Solution: A solution is a substance dissolved in a liquid to form a true solution such as seawater.

A solution is thus a special kind of mixture in which the dispersed particles are of molecular size. Solutions may be composed of any comb1nat ion of the three stages of matter (gases, liquids, solids) but always consist of a single phase.

The components of a solution are called the solvent and the solute, where the solvent is the component present in greater amount than the other, eg in a sugary solution, sugar is the solute and water the solvent.

5.2.8 Molarity

As it is relatively easy to measure volume of a solution, concentration is in this case expressed in terms of known quantity of solute in a given solution. The quantity of solute is stated in moles and the volume in litres.

Definition:
Molarity: A method of describing concentration of a solution.

The symbol for molarity is M. The molarity of a solution is thus an expression of the number of moles of solute per litre of solution.

A one molar solution contains 1 mole of solute per litre of solution. Solutions of the same molarity have the same concentration of solute molecules.

Worked Example 1

One mole of sodium chloride (NaCl) has a mass of 58,5 g. This quantity dissolved in exactly 1 litre gives a 1-M solution. Half this quantity in 1 litre forms a 0,5-M solution and twice the quantity yields a 2-M solution.

Solutions of known molarity are usually prepared in volumetric flasks. Molarity is preferred when volumes of solutions are to be measured.

5.2.9 Suspensions

Suspensions are substances which do not dissolve in particular liquids, eg sand and water. Filtration through sufficiently fine filter paper will remove suspended matter.

5.2.10 Colloidal suspensions

Fine substances which remain suspended indefinitely and cannot be filtered out through the finest filter paper. Colloidal particles can be removed by means of appropriate membrane filters or flocculation and sedimentation processes.

Definition:
Colloidal: A system in which finely divided particles, which are approximately 10 to 10,000 angstroms in size, are dispersed within a continuous medium in a manner that prevents them from being filtered easily or settled rapidly.

5.2.11 Chemical symbols

Berzelius, a Swedish chemist, was the first to use letters as symbols for elements. He used the first letter in the name of an element as its symbol, eg 0 represent oxygen and H represent Hydrogen. A number of elements however begin with the same letter.

In such cases, a second minor letter is added whose sound is conspicuous when the name of the element is pronounced eg C stands for carbon, Ca for calcium, Cl for chlorine, Cr for chromium and Co for cobalt.

The first letter of a symbol is always capitalised followed by a second minor letter. If the second letter is also capitalised, everything will change, eg Co stands for cobalt while CO represents the compound carbon monoxide which is completely different.

In several cases the symbol is derived from the Latin name of the element, eg Fe stands for iron (from the Latin ferrum) while Pb, the symbol for lead comes from the Latin word plumbum.

A chemical symbol is more than an abbreviation, it has also quantitative significance. The symbol 0 does not only represent oxygen but also stands for one atom of oxygen.

The expression 20 means 2 atoms of oxygen. The atom is the smallest unit of an element that can enter into combinations with other elements.

5.3 Gases: Solubility in liquids and effect of temperature and pressure on equilibrium

Dissolved gas concentrations are usually expressed as part per million or milligram per liter.

The temperature of a gas is an indication of the average kinetic energy of its molecules. The higher the temperature, the more kinetic energy it possesses and the more rapidly they move about.

The pressure which a gas exerts on the walls of its container is the result of the collisions of gas molecules with the walls.

Thus if the volume of one mole of gas molecules remains constant, the pressure exerted by the gas increase as its temperature is raised. It follows that the pressure exerted by one mole of gas decrease as the temperature is lowered.

Furthermore, if the pressure exerted by one mole of gas molecules is to remain the same as the temperature increase, the volume which the gas occupies must increase.

Since the molecules move faster at higher temperatures, it strikes the walls of the container more frequently and with more force. If the volume of the container is increased, the pressure will remain the same.

On the other hand, if the pressure remains constant and the temperature decrease, the volume of one mole of gas molecules will decrease.

Both temperature and pressure should thus be considered when measuring the volume of a gas. Because of this, it is helpful to have a standard temperature and standard pressure for use in measuring and comparing gas volumes.

Important:
Standard temperature is defined as exactly 0 °C while standard pressure exerted by a column of mercury exactly 760 mm high is 101,3 kPa or 1,013 Bar. 101,3 kPa is also known as the absolute zero or atmospheric pressure.

5.3.1 Solubility of gases

a) Pressure and solubility

The solubility of gases in liquids and solids is measurably affected by changes in pressure. When the pressure is increased, the concentration of dissolved gas increases.

The solubility of a gas is thus directly proportional to the pressure of the gas above the liquid. Oxygen, hydrogen and nitrogen (less dense than air) are only slightly soluble in water while ammonia, carbon dioxide and sulphur dioxide which are denser than air, are more soluble.

Hydrogen sulphide is a very poisonous gas and dissolves in water to form a weak acid called hydro sulphuric acid. Carbon dioxide dissolve readily in cold water and a few molecules may even unit with water molecules to form carbonic acid.

b) Temperature and solubility
Solubility of a gas decrease with an increase in temperature. Raising the temperature of a solution increases the average speed of the molecules which leave the solvent at a faster rate than entering.

c) Salinity and solubility
Another factor which influences solubility is the salt concentration (salinity) of water. The higher the salinity, the less oxygen will be in solution and vice versa.

In dealing with concentration of gases such as H_2S, CH_4, Cl_2 etc. in air, the term parts per million by volume is often used.

5.4 Organic and inorganic compounds

The basic laws of chemistry are the same for organic and inorganic chemistry. The behaviour of these compounds however differs.

All organic compounds contain carbon atoms connected to each other in chain or ring structures with other elements attached to it. Major components are carbon, hydrogen and oxygen.

These molecules can be oxidised to stable end products. Organics are derived from nature.

In contrast to inorganic compounds, organic substances are usually combustible, high in molecular mass, only sparingly soluble in water reacting as molecules rather than ions and are a food source for animal consumers and microbial decomposers.

Important:
Inorganic substances generally have no carbon in their structure and have mineral origin.

5.5 Cations and anions occurring in water

When in water, inorganic compounds dissociate into electrically charged atoms and radicals referred to as ions.

An ion is represented by the chemical symbol of the element, or radical, followed by superscript + or – signs to indicate the number of unit charges on the ion, e.g. Na^+, Cl^-, Al^{++}, NH_4^+ and $SO_4^=$.

Those carrying + charges are called cations while atoms having gained electrons to become negatively charged are called anions.

Laboratory rests (titrations) determine the concentrations of particular ions in solution. Test results are normally expressed as mass of the element or radical in mg/l of water.

5.6 Oxidation and reduction

Any chemical reaction involving the loss of one or more electrons by an atom or ion is called oxidation. The particle losing the electron is said to be oxidised, e.g. Na - electron - Na^+. This reaction is called oxidation.

A chemical reaction involving the gain of one or more electrons by an atom or ion is called reduction. The particle gaining the electron e.g. Cl - electron - Cl^- is said to be reduced.

The substance which is reduced received electrons from the oxidised substance and is called the oxidising agent. At the same time, the substance which is oxidised has transferred electrons to the reduced substance and is called the reducing agent.

Definition:
Oxidation: The process or result of oxidizing or being oxidized.

The total number of electrons lost by one substance upon oxidation is always equal to the total number of electrons gained by another substance in the accompanying reduction process.

Definition:
Reduction: The action or fact of making a specified thing smaller or less in amount, degree, or size.

The process of ordinary combustion as in a fire, is also a process of combining oxygen and thus an oxidation reaction. The resulting compounds are called oxides.

Carbon oxidises to carbon dioxide, hydrogen to water or hydrogen oxide, iron to rust (iron oxide), sulphur to sulphate (sulphur dioxide) etc.

Oxidation is always accompanied by a release of energy in some or other form, usually heat. Oxidation is very important in the purification process and is carried out mainly by millions of aerobic micro-organisms and also even bigger organisms. Oxygen required is obtained from the atmosphere.

In addition to oxidation by atmospheric oxygen, there are several other ways in which oxidation can occur.

Some chemical compounds are rich in oxygen, eg Potassium permanganate, and will release some of it under the right circumstances. This can be used to measure how much oxygen is required to oxidise substances.

Chemicals such as chlorine can cause indirect oxidation. In combination with water, hypochlorites are formed which ultimately become hydrochloric acid and release 0 in the process.

Hydrogen sulphide (H_2S) can be oxidised to water and sulphur dioxide. Sulphur bacteria can also oxidise H_2S to water and free sulphur which is then further oxidised to sulphur dioxide ($S0_2$). This compound dissolves in water to form sulphuric acid which is corrosive towards concrete.

Fermentation of sugars by yeast is also a form of oxidation but no external oxygen is needed. It is carried out 'internally' in the molecule by anaerobic bacteria.

Anaerobic reactions are oxidative and energy- releasing and differ from aerobic reaction chiefly in the fact that no external sources of oxygen are necessary.

5.7 Dissociation, ionisation, H+, OH-, Acids, Bases and pH

Dissociation is the separation of ions from the crystals of ionic compounds during the solution process.

For **example**, when NaCl is dropped in water, water dripoles exert attractive forces on the ions of the salt crystals.

These forces weaken the ionic electrovalent bond which holds the sodium and chloride together in the crystal lattice. The ions then break away and loosely bind to the water molecules until the crystal is completely dissolved and the ions dispersed throughout the solution.

$NaCl + H_2O \rightarrow Na^+ + Cl^- + H_2O$

Sodium chloride thus dissociate when dissolved in water. The ions are said to be hydrated.

Covalent bonds can be polar if the two atoms of the molecule have a distinctive negative and positive region. When polar molecules dissolve in water, the water dipoles weaken the bond and pull the molecules apart.

These portions of the polar solute molecules become hydrated as ions (which were formed in the hydration process).

Definition:
Polar: The straight line joining the two points at which tangents from a fixed point touch a conic section.

The formation of ions from polar solute molecules by the action of the solvent is called ionisation. Take as example water which is molecular in structure with a single covalent polar bond:

$H_2O + H_2O \rightarrow H_3O^+ + OH^-$

The hydrogen ion, H_3O^+, act as a hydrogen ion (H^+ or proton).

Due to the fact that water yields one hydroxyl (basic) ion for each hydrogen (acidic ion), pure water is considered neutral.

$H_2O \rightarrow H^+ + OH^-$

The acidic nature of water is related to the concentration of hydrogen ions in water solution by use of the symbol pH, where

$\text{pH} = \frac{1}{\log \text{H}^+}$

Since the logarithm of $\frac{1}{10^{-7}}$ is 7, the pH at neutrality is 7.

When an acid is added to water, the hydronium ion concentration increases resulting in a lower pH number.

Conversely, when an alkaline substance is added, the hydroxyl ions unite with free hydrogen ions, lowering the hydrogen ion concentration, thus causing a higher pH. The pH scale ranging from 0 to 14 is acidic from 0 to 7 and basic from 7 to 14.

Compounds whose watery solutions contain ions are traditionally classed as acids, bases and salts.

The term acid and base apply to two groups of compounds with opposing sets of characters. Different chemists define acids and bases differently.

According to Arrhenius, an acid is defined as a substance which release protons in aqueous solutions while a base is a substance which releases hydroxide ions in solution.

Bronsted-Lowry defined an acid as a substance which release protons (proton donor) and a base as a substance combining with protons proton accepter).

According to Lewis, an acid is a molecule or ion able to accept an electron pair from another molecule or ion while a base is a substance that can share its electron pair with an acid.

Thus an acid is an electron-pair accepter and a base is an electron-pair donor.

Acids which ionise completely or nearly so, in watery solutions provide high concentrations of hydronium ions. Such concentrations characterise strong acids, e.g. H_2SO_4 and HCl.

Substances producing few H_3O^+ ions in watery solutions such as acetic- and carbonic acid are weak acids. They ionise slightly in water, even in very dilute solutions.

Hydroxides of active metals e.g. NaOH and KOH are very soluble in water. Their solutions are strongly alkaline because of the high concentration of strong basic (OH^-) ions.

We thus speak of strong basic solutions. The strength of the base depends on the concentration of OH^- ions in solution.

Ammonia water solutions are weakly basic because of a low concentration of OH^- ions. NH_3 is not a strong base. Milk of Magnesia ($Mg(OH)_2$) is also known as a weak base.

Acid added to water dissociate into hydrogen ions and anion radicals resulting in an acidic solution, eg:

$H_2SO_4 \rightarrow H^+ - SO_4^=$

A basic solution is formed by adding an alkali such as NaOH to water. If both an acid and base are dissolved in the same water, the H^+ ions will combine with the OH^- ions to form H_2O.

If equivalent amounts are added, it neutralises each other forming a salt solution.

5.8 Alkalinity and buffer capacity

Alkalinity of water is a measure of its capacity to neutralise acids, in other words, to absorb hydrogen ions without significant pH change. Alkalinity is measured by titrating against a standard strength of sulphuric acid.

The results obtained is calculated and expressed as mg/l $CaC0_3$.

A buffer is a solution composed of a weak acid and a salt containing the same cation. A mixture of HCN and NaCN is solution is an example of a buffer.

Because of the fact that it contains a reservoir of both ionic and molecular species, it is capable of maintaining a nearly constant pH upon addition of small amounts of strong acid or base.

The buffer capacity is thus the ability to maintain the pH in spite of acid or base additions.

5.9 Concentration of chemical reagents, mole versus normality

Molarity and normality are concentration units useful in studying the chemical properties of the solute. These units are on the basis of mass/volume where measured amounts of solute is in sufficient sol vent to give a solution of specific volume.

The molarity (M) of a solution is the number of moles of solute per litre of solution. A 1-molar (1-M) solution contains 1 gram molecular mass of chemical per liter of solution.

For example: one molar solution of NaOH would contain 40,0 g (Na = 23; 0 = 16; H = 1) of the pure salt dissolved in water.

Normality is the concentration system for solutions containing a specified number of equivalent weights (or equivalents) of solute per liter of solution.

A 1 normal (1 N) NaOH solution contains 1 g equivalent mass of reagent per litre of solution. A normal NaOH solution would contain the same amount of salt as the 1-M solution, since the mole mass and equivalent mass are identical.

However, in the case of sulphuric acid, a 1-M solution would contain 98,1 g/l whereas a 1 N solution would contain 49,0 g/l. Thus a 0,5 N solution of H_2SO_4 contains half an equivalent (or one quarter of a mole) of H_2SO_4 per litre solution.

An equivalent is that amount of chemical species stoichiometrically involving the gain, loss or sharing of an Avogadro* number of electrons.

Important:
*(The amount of substance containing the Avogadro number of any kind of chemical unit is called a mole of that substance e.g. 12,011 g of carbon-12 is a mole of carbon-12 atoms and 1,0080 of Hydrogen-1 is a mole of hydrogen-1 atoms. Mole is used by chemists the way a grocer uses dozens or gross.

An equivalent can also be defined as follows:

Equivalents are the quantities of substances that have the same combining capacity in chemical reactions.

Definition:
Stoichiometry: Calculation of the quantities of reactants and products in a chemical reaction.

5.10 Adsorption

Adsorption is the concentration of a gas, liquid or solid on the surface of a liquid or solid with which it is in contact. Charcoal for example is denser than water but it often adsorbs enough gas to make it float on water.

This ability to adsorb is the most remarkable physical property of charcoal.

Activated charcoal used for adsorption of gases have a small pore structure. It is used in gasmasks, for the recovery of volatile solvent vapour, the removal of impurities from gases in industrial processes and purification of product water in food and beverage industries.

It is also used to remove odours from air in air-conditioning systems and the most important for our purpose, to remove impurities responsible for objectionable taste and odour in water treatment.

Definition:
Adsorb: To gather (a gas, liquid, or dissolved substance) on a surface in a condensed layer.

Activated carbon can be prepared from hardwood charcoal, lignite, nutshells or other carbonaceous materials by controlled combustion to develop adsorptive characteristics. Activated charcoal is available in powdered and granular form.

5.11 Periodic table of elements

In the 18th century a Russian chemist Mendeleyev devised a useful classification system for elements which he called the Periodic Table of Elements.

Elements with similar properties and same number of electrons in the outermost energy level are grouped one below the other in Groups I to VIII. Elements with the same number of energy levels are grouped in Periods from left to right.

He also noticed when elements are arranged in order or increasing atomic weight, the chemical properties follow a pattern.

The Periodic Table of Elements in use today are based largely upon the pioneer work done by Mendeleyev and serves as a useful and systematic classification of elements according to their properties which makes the study of chemistry easier.

Activity 5.1

1. Name 5 uses of activated carbon.
2. Define:
   (a) alkalinity
   (b) buffer capacity
   (c) collidal suspension
   (d) pH of natural water
   (e) suspension
   (f) oxidation
   (g) reduction
3. Give the names of the following:
   CO_2, H_2S, OH^-, NH_4^+, $SO_4^=$, H_3O^+

Self-Check

I am able to:	**Yes**	**No**
• Understand general chemistry		
o elements		
o atoms		
o atomic mass		
o valency		
o compounds		
o mixtures		
o solutions		
o molarity		
o suspensions		
o colloidal		
o suspensions		
o chemical symbols		
• Describe gases, their solubility in water and the effect temperature on the equilibrium		

o CO_2		
o O_2		
o H_2S		
• Describe organic and inorganic compounds		
• Describe cations and anions occurring in natural water		
• Describe oxidation and reduction		
• Describe dissociation, ionisation		
o H^+		
o OH^-		
o acids and bases		
o pH		
• Describe alkalinity and buffer capacity		
• Explain the concentration of chemical reagents; mole versus normality		
• Describe adsorption		
• Understand the periodic table of elements		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 6

Elementary Water Biology

Learning Outcomes
On completion of this module, students should be able to:

- Describe the classification of micro-organisms
- Explain micro-organism types
  - bacteria
  - viruses
  - algae
  - protozoa
  - amoeba
  - other micro-organisms
- Describe aquatic plants
  - water lettuce
  - hyacinths
  - duckweed
  - daphnia
- Explain waterborne diseases
- Understand pollution detection with E coli as pollution index
- Describe nutrients

6.1 Introduction

Microbiology is the science of microscopically small life. One group of microorganisms which is especially of importance to us is bacteria. Use is made of them in water treatment which makes knowledge of it an important aspect.

6.2 Microorganisms

6.2.1 Classification

Definition:
Microorganism: a microscopic organism, especially a bacterium, virus, or fungus.

All living organisms are classified as follows (see **Figure 6.1**):

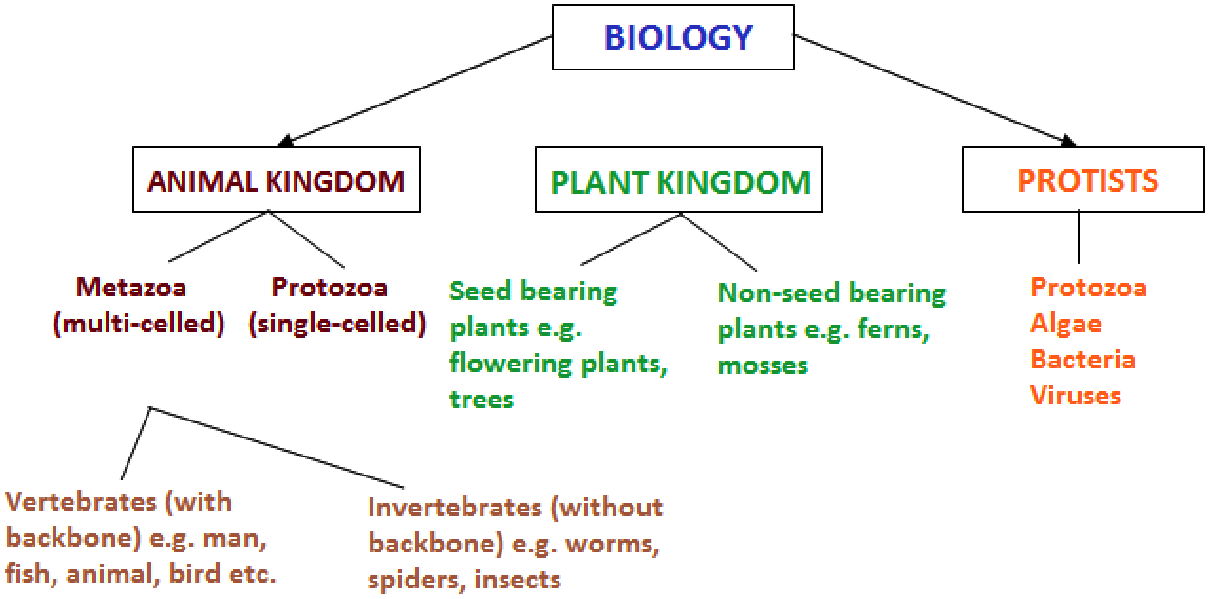


Figure 6.1 Classification of all living organisms

It is not easy to classify microorganisms as some have both plant and animal characteristics. Viruses on the other hand appear to be unrelated to both kingdoms.

For this reason, a separate kingdom namely Protists has been established to accommodate these organisms. Protists vary in size from 100 μm to 0,02 μm. Some are thus visible with the naked eye while others can only be seen through a powerful microscope.

A binomial system is used to name bacteria. The first word is the genus name; the second is the species name, e.g. Eschericia coli. The genus name is always written with a capital letter and the species name with a minor letter.

Since bacteria are so small, they can only be roughly identified and classified by observation under a microscope. Various bacteria behave different when allowed to grow in selected nutrient media, e.g. sugar, lactose, etc.

Some produce gas; others have a metallic lustre, etc. These and other variations with different nutrients are helpful in identification.

6.2.2 Other classification systems

Bacteria and other microbes can also be classified according to their behavioural characteristics:

- **According to respiration**

  - **Aerobic**: organisms require free oxygen in air or dissolved in water in decomposing organic matter to gain energy for growth and multiplication.

- **Anaerobic**: organisms thrive in the absence of oxygen. They obtain the oxygen required by breaking down oxygen containing compounds such as nitrate and sulphate.

- **Facultative anaerobes**: grow best in the presence of 02 but can also grow in its absence. If deprived of 02, they need an organic carbon source for oxidation.

- **According to food preferences**
  Autotrophic: (self- feeding) aerobic organisms which obtain their energy from the oxidation of simple inorganic compounds of N, H and S. They obtain the carbon necessary for their structure from CO_2.

- **Heterotrophs**: (also called saprophytes) can be aerobic, anaerobic or facultative and use organic matter as both an energy and carbon source for synthesis. The primary reason heterotrophs decompose organics is gain of energy for synthesis of new cells, respiration and motility.

- **Photosynthetic autotrophic bacteria**: derive their energy from the sun and inorganic compounds e.g. N and P. An example of this group is algae.

- **Psycrophylic**: (or **cryophilic**) organisms thrive at an optimum temperature of 8 °C.

- **Mesophylic**: bacteria thrive at 37 °C.

- **Thermophylic**: organisms perform best at = 55 °C.

6.3 Types of micro organisms

Although bacteria are the most abundant in water pollution control, many other families are also of concern.

6.3.1 Bacteria

Bacteria are simple, colourless, one-celled organisms using soluble food and are capable of self-reproduction without sunlight. They play an indispensable role as decomposers in the decay of organic matter in nature.

They range in size from approximately 0,5 μm to 5 μm and are therefore only visible through a microscope. Some species from spores with tough coatings that are resistant to heat, lack of moisture and loss of food supply as a means of survival.

Large numbers of bacteria may be found in untreated (raw) water. Whilst most of them are harmless, others may be pathogenic. The coli form group of bacteria is of great importance and includes E.coli which normally inhabits the intestinal track of man and animal.

It is considered non-pathogenic but is used as a pollution index. They do not increase in numbers in water but may be found in fresh water for weeks up to months. The death rate is much higher in saltwater due to lower dissolved oxygen concentration.

6.3.2 Viruses

Viruses are obligate, intracellular parasites that replicate only in living hosts cells. They are composed largely of nucleic acid and protein and lack the metabolic systems for self-reproduction and are approximately one fifth the size of bacteria.

Viruses of concern in water pollution are those found in the intestinal track of humans, e.g. adenovirus, coxsackie virus, echinovirus, poliovirus and infectious hepatitis.

Infectious hepatitis is the only viral infection proven and documented to have been transmitted by drinking water, causing outbreaks of disease.

6.3.3 Algae

Algae are microscopic photosynthetic plants of the simplest forms, having neither roots, stems or leaves. They are chlorophyll bearing, unicellular, and occur in varying shapes and sizes. Certain types are filamentous.

Large numbers of algae cause turbidity, taste and apparent colour which is difficult to rectify (odours usually start once the algae die off and can be fishy, muddy or aromatic). Furthermore it clogs filters.

Algae are also autotrophic, using CO_2 or bicarbonates as a carbon source and inorganic nutrients such as phosphates and nitrogen, as ammonia or nitrate. In addition certain trace elements are required such as magnesium, cobalt, boron and calcium.

The products of photosynthesis are oxygen and new plant growth. Energy for photosynthesis is derived from light. Excessive algae growth is normally due to pollution of water sources.

Definition:

Photosynthesis: the process by which green plants and some other organisms use sunlight to synthesize foods from carbon dioxide and water.

6.3.4 Protozoa

Protozoa are much larger than bacteria and identification is usually microscopic. Some may be amorphous e.g. amoeba, those with distinctive shape such as ciliates and other with flagellas which are able to move.

Protozoa are aerobic organisms plentiful in still water where large numbers of bacteria are present and as parasites in animals.

Some protozoans are also pathogenic e.g. those which cause amoebic dysentery and malaria. Under adverse conditions they form cysts which are similar to spores of bacteria.

Definition:
Protozoa: single celled aquatic animals which consume bacteria, algae and organic matter.

6.3.5 Amoeba

Amoeba is also a type of protozoa which move and ingest food through the action of mobile protoplasm.

6.3.6 Other micro organisms

Rotifers are simple multi-cellular aerobic animals that metabolise solid food. They are found in natural waters and stabilisation ponds. Crustaceans are multi cellular animals, typically 2 mm in size and easily visible.

In the aquatic food chain they serve as herbivores, ingesting algae and in turn being eaten by fish. Other organisms may include protists which can be very troublesome fungi which grow in the absence of light, produce unpleasant tastes and odours.

They may even cause clogging and actinomycetes which are responsible for earthy, musty and muddy odours to water.

6.4 Aquatic plants

Macrophytes are aquatic photosynthetic plants, excluding algae that occur as floating, submerged and immersed types. Duckweed is a small 3-leafed, floating plant about 5 mm in diameter riding on water surface. Hyacinths also float on water.

Pondweed, waterweed and coontail grow beneath the water (submerged).
These may root at depths greater than 3 m below the surface, depending on water clarity.

Immersed plants such as pickerel weed and cattail, attached by roots to the bottom mud, extend their principle foliage into the air above the surface. Disposal of wastewater can promote weeds when conditions such as temperature and sunlight are favourable.

6.4.1 Daphnia

Forms part of the group crustaceae. Daphnia act as filters in water in that it takes in water, let it flow out of its body again while retaining food particles in its body. These organisms are in abundance in maturation ponds where it aid in purifying effluent to a higher quality.

6.5 Waterborne diseases

The most common waterborne bacterial diseases are typhoid fever caused by Salmonella typhii, cholera (Vibrio cholerae) and bacillary dysentery (Shingella dysenteriae). These diseases are all fatal.

Entamoeba hystolitica, causing severe amoebic dysentery and Giardia lamblia, causing a less severe gastro-intestinal infection, are two waterborne parasitic protozoa.

Entamoeba hystolitica in its various stages is not very resistant to purification. The disease can however be spread by eating raw and inadequately washed vegetables which have been irrigated with fresh sewage or sewage sludge.

Waterborne outbreaks of infectious hepatitus have occurred, although direct contact is still the main means of transmission. Bilharzia is a parasitic disease caused by a small, flat worm that infects human internal organs.

Eggs of these worms are passed into water with faecal discharges. They hatch into miracidia, enter snails, develop into sporocysts, leave the snail and bore into the skin of humans for re-infection.

6.6 Pollution detection: Escherichia coli as pollution index

Since it is difficult to test for the presence of different pathogens, the bacterial quality of water is based on testing for non-pathogenic indicator organisms, principally the coliform group.

Coliform bacteria, as typified by E.coli and faecal Streptococci, residing in the intestinal track of humans are excreted in large numbers (± 3 million per 100 ml sample) in faeces of humans and warm- blooded animals.

Pathogenic bacteria and viruses causing enteric diseases originate from the same sources. Consequently water contaminated by faecal pollution is identified as potentially dangerous by the presence of coliform bacteria.

Drinking water standards specify that water is safe if it contains nil E. coli per 100 ml sample.

6.6.1 Detection by bacterial tests

The main methods for identification and counting of bacteria are as follows:

- **Microscopic examination**: by fixation and staining of fresh specimens, bacteria can be examined under the microscope.

- **Culture**: a suitable growth medium is inoculated with the organism of interest and the resulting culture studied. Different bacteria will behave differently on different growth media and can be identified according to it.

Definition:
Culture media: special formulations of organic and inorganic nutrients to support the growth of micro-organisms.

- **Counting**: the most positive method is to filter a sample through a very fine membrane and then placing the membrane on a suitable culture medium. Incubate and count the number of colonies of the appropriate type.

In both the above methods the indicator species is E.coli. Absence of E.coli indicates safe water.

6.7 Nutrients

Heterotrophs require organic compounds and autotrophs require certain inorganic compounds. In general the most important elements in nutrition are the following:

Carbon	(C)	Hydrogen	(H)
Oxygen	(0)	Nitrogen	(N)
Sulphur	(S)	Phosphorous	(P)

Small concentrations of the following macronutrients must also be available for growing cells for synthesis of enzymes, cell walls, etc.

Calcium	(Ca)	Sodium	(Na)
Iron	(Fe)	Potassium	(K)

Elements such as copper (Cu) and molybdenum (Mo) are growth factors and must be available in trace elements.

Activity 6.1

1. Define the following:
    a) Daphnia
    b) Protozoa
    c) Algae
    d) Viruses
    e) Autotrophic bacteria
2. Name six nutrients required for micro organism growth.
3. Classify bacteria according to respiration.
4. Name three waterborne diseases.
5. Name the main methods of identifying and counting of bacteria

Self-Check

I am able to:	**Yes**	**No**
• Describe the classification of micro-organisms		
• Explain micro-organism types		
o bacteria		
o viruses		
o algae		
o protozoa		
o amoeba		
o other micro-organisms		
• Describe aquatic plants		
o water lettuce		
o hyacinths		
o duckweed		
o daphnia		
• Explain waterborne diseases		
• Understand pollution detection with E coli as pollution index		
• Describe nutrients		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 7

Legislation

Learning Outcomes
On completion of this module, students should be able to:

- Understand appropriate sections of the Law
  - Act 22 of 1941
  - Act 54 of 1972
  - Act 63 of 1977
  - Act 100 of 1982
  - Act 54 of 1956
  - Act 96 of 1984
- Describe provincial ordinances and by-laws
- Explain the requirements for the purification of water for domestic supplies (SABS 241 of 1984)
- Explain the requirements for the purification of wastewater and effluent (Government notice 991 of 18 May 1984)

7.1 Introduction

The objective of this module is to make you aware of protection - water and effluent by different Laws and by-laws. As it is not important to know the different Laws which provide protection of water quality, it is interesting to know of them.

The requirements for effluent and potable water are, however, very important and these you should know well.

7.2 Legislation

Sections in the following Acts provide legislation for water quality standards:

- Act 22 of 1941 Factories, Machines and Building Works Act
- Act 54 of 1972 Act on foodstuffs, cosmetics and disinfectants
- Act 63 of 1977 Health Act
- Act 100 of 1982 Environment conservation Act
- Act 54 of 1956 Water Act
- Act 96 of 1984 Water Act amended.

Water Act 54 of 1956 provided for the acquisition of water rights for municipal and industrial purposes. Bearing in mind looming shortages in the country's gross water supplies, effluents resulting from municipal and industrial water are indispensable to supplement natural run-off.

All such effluents are therefore considered public water. The Water Act was amended in 1984 to eliminate shortcomings in the 1956 Act, by vesting wider powers in the State to control industrial water use and to control water pollution.

7.3 Provincial ordinances and local by-laws

The different provinces and municipalities in the RSA promulgate ordinances and by-laws such as the Standard drainage by-laws published in the Administrators notice 665 of 8 June 1977 in the Transvaal.

These by-laws lay down general provisions regarding common drains, approval of plans, drains and manholes, etc. It therefore also controls the quality and quantity of effluent to be discharged.

7.4 Requirements for domestic water

This specification (SABS 241 of 1984) lays down the minimum physical, chemical and bacteriological requirements for the purity (as delivered to the consumer) of water for domestic supplies.

Water for domestic supplies includes water for culinary purposes and general household usage, but not necessarily water for hot water systems. Refer to Module 9 for specifications for potable water.

7.5 Requirements for wastewater effluent

In Government notice 991 of May 1984, the Minister of Environment Affairs and Fisheries, Minister S A Hayword, prescribed requirements for the purification of Wastewater and effluent produced by or resulting from the use of water for industrial purposes, by virtue of powers vested in him in section 21(1) (a) of the water Act of 1956.

According to this notice, two sets of standards namely a special standard and a general standard were laid down. Special standards apply to wastewater or effluent arising in the catchment area draining water to any river specified in schedule I or a tributary.

Thereof at any place between the source thereof and the point mentioned in the schedule, in so far as such catchment area is situated within the territory of the RSA.

7.5.1 Special standard for phosphate

Wastewater or effluent arising in the catchment area within which water is drained to any river specified in schedule II or tributary thereof at any place between the source thereof and the point mentioned in the schedule.

In so far as the catchment area is situated in the territory of the RSA, shall not contain soluble ortho phosphate (as P) in higher concentration than 1,0 mg;

General standards apply for wastewater or effluent arising in any area other than in which the special standard is applicable.

Activity 7.1

1. Explain why it is necessary to understand legislation regarding water treatment.

Self-Check

I am able to:	**Yes**	**No**
• Understand appropriate sections of the Law		
o Act 22 of 1941		
o Act 54 of 1972		
o Act 63 of 1977		
o Act 100 of 1982		
o Act 54 of 1956		
o Act 96 of 1984		
• Describe provincial ordinances and by-laws		
• Explain the requirements for the purification of water for domestic supplies (SABS 241 of 1984)		
• Explain the requirements for the purification of wastewater and effluent (Government notice 991 of 18 May 1984)		
If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 8

Watersources

Learning Outcomes

On completion of this module, students should be able to:

- Describe the natural water cycle
- Describe the types of water
  - soft
  - hard
  - brackish
  - coloured
  - turbid
- Describe watersources
  - underground waters
  - surface waters

8.1 Introduction

In this module the natural water cycle, types of water and water sources are discussed. On completion, you should know the definitions, be able to draw the water cycle and classify water sources.

8.2 Natural water sources

The world's supply of fresh water is obtained almost entirely as precipitation resulting from evaporation. The continuous circulation of water by evaporation from the hydrosphere to the atmosphere and its subsequent precipitation back to the hydrosphere is referred to as the hydrologic cycle.

Although this cycle is continuum, its usual description begins with the ocean (± 71% of the earth's surface) which evaporates into the atmosphere due to the heat of the sun.

Definition:

Hydrosphere: all the waters on the earth's surface, such as lakes and seas, and sometimes including water over the earth's surface, such as clouds.

Normally water vapour is invisible, but under certain conditions of super saturation it forms clouds which are meta-stable.

Under the influence of certain changes in temperature and/or pressure, the moisture condenses and returns to the earth in the form of hail, rain, sleet or snow-collectively referred to as water of meteoric origin. Below, **Figure 8.1** illustrates the water cycle.

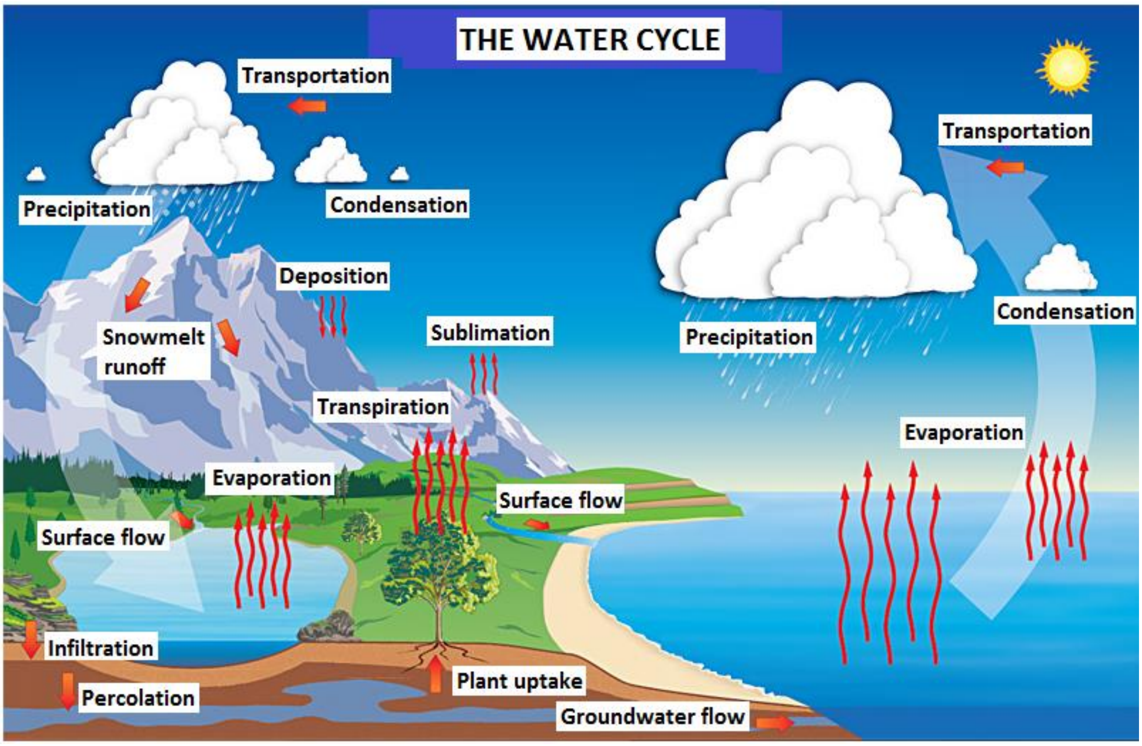


Figure 8.1 The Water Cycle

8.2.1 The first stage

The first stage in the hydrologic cycle is evaporation. It is a physical process whereby water is transformed into water vapour. All water that falls in the ocean or is discharged to it from the earth's surface is finally returned to the atmosphere by this process.

The vapour is carried by moving air masses and when cooled down to its dew point, it condenses into visible water droplets which form clouds or fog. Evaporation will continue as long as a difference in vapour pressure exists if the water surface is reasonably close to the soil surface.

The amount of evaporation from land surfaces depend on the amount of moisture available, which in turn depends upon the rainfall and those characteristics of the soil which affect infiltration, absorption and percolation.

It is also influenced by temperature of air and water, barometric pressure, wind velocity and solar radiation.

Water taken from the soil by roots of vegetation and discharged into the atmosphere as vapour is known as transpiration. This causes a considerable reduction of run-off.

Transpiration rate is independent of plant species but depend upon root depth and percentage cover (and thus indirectly on the plant type).

8.2.2 The second stage

The second stage in the process is condensation. This capacity of the atmosphere to retain moisture is a function of temperature.

Therefore when the temperature falls below dew point (ie temperature at which atmosphere becomes saturated with water vapour) condensation occurs.

Wind drives these clouds over land – and sea areas, clm1ds accumulate, grow bigger and heavier and under suitable conditions precipitation may occur.

8.2.3 The third stage

The third stage in the cycle is precipitation and is the primary source of surface and ground water. Precipitation occurs when moisture is transferred to the earth from the atmosphere.

Rainfall is the ultimate source of all groundwater and the amount entering the underground reservoirs depends in part upon the distribution and intensity of the rain. Surface run-off comes from three sources:

- rainfall that remains after losses due to soil infiltration, evaporation and transpiration
- water released from storage and
- water emerging from underground reservoirs

Run-off appears as stream flow and is expressed in m^3/s. Infiltration is the entrance of rainwater into the ground. Percolation is the movement through the soil after infiltration. Infiltration replenishes groundwater and may reappear as streams.

Definition:
Percolation: the slow passage of a liquid through a filtering medium; "the percolation of rainwater through the soil".

The amount of infiltration may depend upon the following:

- rainfall characteristics
- soil characteristics
- soil cover

Surface water is often contained in water bodies e.g. lakes, swamps which act as reservoirs to collect and detain water during heavy run-off and later release it at a uniform rate.

At its absence artificial basins such as dams are created for multiple uses such as irrigation, power generation, water supply and recreation. It also served the purpose of controlling flooding.

8.3 Types of water

8.3.1 Hard water

Contains appreciable amounts of Ca - and Mg - salts (120 - 180 ppm) originating from the ground through which it flows. Soap does not lather easily in hard water.

Hardness of water is of prime concern for many applications because of its scale forming tendencies. For practical purposes hardness may be defined as the characteristics of water representing the concentration of Calcium and Magnesium ions.

Although other ions in water such as iron and manganese can cause hardness, these are present in very small concentrations and are not, therefore, of any real significance to water's hardness.

- **Permanent and temporary hardness**

Calcium and Magnesium can be present in water in the form of different salts commonly as bicarbonates, carbonates, sulphates and chlorides. On boiling, calcium and magnesium bicarbonates decompose to their carbonates which have a low solubility in water.

Therefore, most of the hardness caused by calcium and magnesium as bicarbonates and carbonates can be removed by boiling. Hardness due to carbonate and bicarbonate salts is known as temporary hardness.

Other salts of calcium and magnesium, such as sulphates and chlorides, are unaffected by boiling. Hardness caused by such salts is known as permanent hardness; alternatively as non-carbonate hardness. Hardness is expressed as mg/l $CaCO_3$.

8.3.2 Soft water

Contains very few Ca and Mg salts (up to 60 ppm total hardness salts) e.g. rainwater or water from fountains.

Soap lathers easily in soft water. For industrial uses, particularly at elevated temperature, the solvent characteristics of soft water (due to absence of deposits on pipelines) can cause corrosion.

8.3.3 Brackish water

Contains 1 500 to 6 000 ppm total dissolved solids (eg $MgSO_4$, NaCl, $NaCO_3$, etc) which affects the taste of water and may cause diarrhoea.

8.3.4 Coloured water

Colour in water is caused by substances dissolved or as colloidal particles in water. It can be distinguished from turbidity in that turbidity influences the apparent colour of water while colour does not influence turbidity. The term apparent colour and actual colour must be distinguished from one another:

- *Apparent colour:* measured in the presence of turbidity in water.
- *Actual colour:* measured once the turbidity has been removed from the water. Both are measured in Hazen units or in mg/1 on the platinum scale. Turbidity decreases clarity of water and results from finely divided impurities in suspension.

  It can be caused by clay particles, living or dead organisms, silt or other material. It can be expressed as mg/l or in Nephelo Turbidity Units (NTU).

8.4 Water sources

8.4.1 Underground water

This is a very important water source. The main source of groundwater is precipitation which may penetrate the soil directly to the groundwater or may even surface streams and percolate from these channels to the groundwater.

It is also derived from wells, springs, boreholes, artesian boreholes, mining activities, etc. Underground water flow comprises an estimated 33 – 407% of the total average run-off.

It is advisable to have underground water analysed before use for domestic purposes or irrigation to determine whether it complies with the standards set for the specific purpose.

Minerals in underground water vary according to the geological formation in which they are contained or through which they have passed. Toxic concentrations of nitrates and fluorides may occur in underground water in certain regions. Salts such as magnesium sulphate usually cause diarrhoea.

The clarity of underground water is usually satisfactory but reduced iron and manganese in solution may cause water to be turbid after exposure to O_2 in the atmosphere.

Groundwater has the following advantages:

- mostly requires no treatment
- cheaper than impounding reservoirs

- the available amounts are more certain (i.e. they are not affected by drought in the short run)

Pollution of underground water can be caused by infiltration from nearby pit latrines, septic tanks, graveyards, etc. especially in dolomitic areas where channelling easily occurs.

8.4.2 Surface water

Surface water exists mainly in two distinct water bodies:

- *oceanic* which is the largest and chief source of atmospheric moisture
- *fresh* water bodies which cover small portions of the earth's surface - fresh water is contained in rivers, ponds and lakes

> **Note:**
> Surface water in general, requires more extensive treatment than groundwater and is easily contaminated with natural and manufactured materials.

The chemical as well as physical properties of surface waters are important to water purification. Surface water may be contained in dams, reservoirs, etc. as water-supply drawing directly from a stream may be unable to satisfy the demands of consumers during low flows.

Storage can retain excess water from periods of high flow for use during periods of low flow. In addition to conserving water for later use, the storage of floodwater may also reduce flood damage below the reservoir.

8.4.3 Classification of water resources

- **Classification according to chemical and physical properties**

Amongst the physical properties, turbidity is the most important. For simplicity sake, water is classified into four main groups:

- **Water with high suspended solids content but low colour intensity**

  Most of the inland rivers fall into this group, e.g. Orange, Tugela, Umkomaas, Caledon, Berg and the Vaal upstream of Vereeniging. Water usually contains high salt content which gives it high buffer capacity or makes it corrosive (high NaCl).

  Flocculants such as lime, ferri chloride, cationic polyelectrolytes or floccotan should be more economical to use than alum when treating this type of water.

- **Water with low suspended solids but with high colour intensity**

  Found in the Southern coastal regions of George, Knysna, Steenbras, etc. It usually contains very little dissolved mineral salts and is chemically unstable which makes it corrosive. Due to low pH of water, the buffer capacity is very low. Alum cannot be used as a flocculant as it is.

However after raising the buffer capacity with, for example, slaked lime, sodium carbonate (soda-ash), sodium aluminate, etc. (to ± 6 - 7,5), alum can be used as a flocculant.

Definition:
Flocculant: a substance that promotes the clumping of particles, especially one used in treating waste water.

- **Water low in turbidity, colour and mineral content**
  Found mostly in Limpopo Province, Mpumalanga and KwaZulu Natal. It usually originates from the Drakensberg Mountains or in the regions whose geological formation consists largely of granite. The buffer capacity is also low and water should be treated as in (b).

- **Polluted water resources**
  Pollution can result from air (smoke, gases, etc.), sewage and industrial effluent insecticides, herbacides, fertilisers, etc. Toxic substances may kill organisms and are removed by specific treatment processes.

  Organic matter containing nutrients such as N and P should be avoided as it leads to increased purification costs.

Complete analyses are carried out at least annually, especially if any of the following are observed:

- sudden increase/decrease in pH
- excessive algae growth
- increased colour
- increase in TDS or increase in electrical conductivity
- decrease in O_2 saturation point.

Activity 8.1

1. Define:
   a) Apparent colour
   b) Actual colour
   c) Soft water
   d) Turbidity
   e) Hard water
   f) Temporary hardness
   g) Permanent hardness
   h) Brackish water

2. Which of the following compounds (salts) terms cause permanent hardness, temporary hardness and brackishness of water:
   Calcium bicarbonate, Calcium carbonate, Magnesium chloride, sodium sulphate, sodium carbonate, calcium chloride, calcium sulphate, sodium chloride
3. In which units is colour of water expressed?

Self-Check

I am able to:	**Yes**	**No**
• Describe the natural water cycle		
• Describe the types of water		
o soft		
o hard		
o brackish		
o coloured		
o turbid		
• Describe watersources		
o underground waters		
o surface waters		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 9

Water quality and specifications

Learning Outcomes
On completion of this module, students should be able to:

- Describe water quality
- Explain the purpose of water purification
- Describe the pollution of watersources
  - domestic
  - industrial
- Describe the impurities found in water
  - suspended matter
  - dissolved solids
  - gases
- Explain the terminology regarding impurities in water
- Describe the SABS specifications for domestic water
  - physical requirements
  - chemical requirements
  - toxic substances
  - bacteriological requirements
- Describe eutrophication
- Explain temperature stratification and inversion

9.1 Introduction

In this module the importance of water quality and specifications thereof is discussed. It also includes the purpose of purification and discuss in detail the different impurities found in water.

It is important to know the specifications regarding the different categories. Other topics discussed are eutrophication and the prevention thereof and temperature stratification which have a great influence on the quality of water in deep dams.

Definition:

Eutrophication: the process by which a body of water becomes enriched in dissolved nutrients (as phosphates).

These stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen.

9.2 Water quality

The quality of water is assessed in terms of its physical, chemical and biological characteristics as well as its intended uses, e.g. although distilled water is chemically, physically and bacteriologically pure, its taste is rather bland and it is highly corrosive.

Water collects impurities from the formation in clouds. Some are harmless; others may be aesthetically offensive or even dangerous with respect to intended use.

9.3 Purpose of water purification

Water requires treatment for a number of reasons:

- to remove disease causing organisms
- to make it attractive to eye, nose and taste
- to remove chemicals or toxic substances which may be harmful to humans or animals

9.4 Pollution of water sources: domestic and industrial

Pure water is a tasteless, colourless and odourless liquid consisting of two hydrogen and one oxygen atoms with a chemical formula H_20. Water is an almost universal solvent with the result that most natural as well as man-made substances are soluble in it to some extent.

Consequently water in nature contains dissolved substances, various other substances as well as gases. These substances are often identified as impurities in water.

The types of minerals dissolved in water are characteristic of the geological regions through which the water has passed. Organic matter decays to form substances such as nitrates, nitrites, ammonia, CO_2 and H_2S. CO_2 can cause water to be acidic.

Fertilisers from lands, toxic substances from industries, etc., add to impurities and can also cause pollution of water sources to make it unsuitable for domestic use (heavy metals, colourants, oil, corrosion products, pesticides, viruses, bacteria, sulphur dioxide).

All water supplies (surface or underground), must be of a certain quality before it is suitable for consumption. It is therefore necessary to measure its constituents against standards which are known to be safe values.

9.5 Impurities found in water

The principal impurities are found in water as dissolved, un-dissolved (suspended) substances and gases. As already mentioned, impurities are usually also classified as physical, chemical and bacteriological.

The presence or absence of impurities depends on the source of water, e.g. suspended matter is usually found in surface water, but it would not be expected in groundwater due to the filtering action.

To evaluate whether the impurities and amounts are harmful, one must determine the nature and amount of impurities present, uses to be made of water and the tolerance for various impurities for each use.

9.5.1 Suspended matter

It includes:

- Bacteria (cause illness)
- Algae, Protozoa (taste, smell, turbidity)
- Silt and clay (turbidity)
- Plants (colour and turbidity)
- Suspended matter can be filtered out of the water or settled by flocculation and sedimentation processes

9.5.2 Dissolved solids

Calcium bicarbonate - alkalinity and hardness
Calcium carbonate - alkalinity and hardness
Magnesium sulphate - hardness
Magnesium chloride - hardness and corrosion to boilers
Sodium bicarbonate and – carbonate - alkalinity with a softening effect
Sodium sulphate - foaming in boilers
Sodium fluoride - influences bone structure and teeth
Sodium chloride - taste
Iron - taste, red-brown colour, hardness
Magnesium - black or brown colour to water

These substances can only be eliminated by ion-exchange or distillation methods.

9.5.3 Gases

- Oxygen - causes metals to rust
- Carbon dioxide - acidity and rust to metals
- Hydrogen sulphide – odour, rust due to increased acidity
- Nitrogen - no effect

Gases can be removed by aeration methods.

9.6 Terminology regarding impurities in water

- **Water for domestic use**: water which is safe to drink with a pleasant odour and taste and is suitable for general domestic use. Furthermore it should not be corrosive nor scale forming.

- **Polluted water**: water which contains micro-organisms, chemicals (from industry or other waste products) or sewage which make it unsuitable for general use.

9.7 SABS specifications for domestic water (SABS 241 – 1984)

This specification lays down the minimum physical, chemical and bacteriological requirements for the purity of water for domestic supplies.

Both the limits specified as "recommended" and "maximum allowable" represent water fit for human consumption and domestic purposes.

⚠	**Note**: The recommended limit should if possible, be applied to all water supplied for domestic use. And the maximum allowable limit should never be resorted to unless no other water supply is practically available. In this case, steps should be taken to improve the quality in a reasonably short time.

	Recommended	**Maximum allowable**
Physical requirements		
Turbidity (NTU)	1	5
Colour	29 mg/l of platinum	Not specified
Taste and odour	Not objectionable	
Chemical requirements		
Magnesium (as Mg)	70,0	100,0
Chloride (as Cl)	250,0	600,0
Iron (as Fe)	0,1	1,0
Manganese (as Mn)	0,05	1,0
Sulphate (as SO_4)	200,0	600,0

Electrical conductivity (mS/m)	70,0	300,0
Total hardness (as $CaCO_3$) min	20,0	Not specified
Total hardness (as $CaCO_3$) max	300,0	650,0
pH value, min	6,0	5,5
pH value, max	9,0	9,5
Sodium (as Na)	100 max	400
Toxic substances		
Nitrates and nitrite (as N)	6,0	10,0
Fluoride (as F)	1,0	1,5
Arsenic (as As)	0,1	0,3
Cadmium (as Cd)	0,01	0,02
Cyanide (as CN)	0,2	0,3
Hexavalent chromium (as Cr)	0,05	0,05
Lead (as Pb)	0,05	0,1
Bacteriological requirements		
Coliform organisms/100ml sample	Nil	5
E.coli I/100 ml sample	Nil	Nil
Standard plate count/ml	100	Not specified

Table 9.1 Limits

Water should not contain any other substance not mentioned in Table 9.1 such proportions to make it unsuitable for domestic use.

9.8 Physical requirements

- **Turbidity** is caused by the presence of various substances e.g. clay, suspended organic and mineral substances precipitated calcium carbonate in hard water, aluminium hydrate in treated water, precipitated ferric oxide in corrosive water and microscopic organisms.

  This colloidal matter is so fine that they pass through filter paper. These negatively charged particles need a flocculent (positive charge) to neutralise it, thus enabling it to settle.

  Turbidity is expressed in MTU (Nephelo turbidity units) and is determined by means of a turbidity meter on a filtered water sample. The sample can also be allowed to stand for 1 hour before measurement.

- **Colour** is caused by substances dissolved or present as colloids in water. It may also be due to dissolved iron or pollution with industrial effluent. Colour has to be removed during water purification and the effectiveness of colour removal is therefore an indication of the efficiency of the purification process.

Colour is expressed in Hazen units. 1 Hazen unit represents the colour when 1 mg platinum is dissolved in 1l of water.

Colour should always be determined on a clear sample with the aid of a Lovibond Comparator and colour disc.

- **Taste and odour** are caused by the presence of decomposed organic material and volatile chemicals. Different people perceive taste and odour differently.

  An unpleasant odour can usually be detected by placing 1 l sample in a 2 l glass bottle, shake vigorously and smell. Taste can be removed by means of activated carbon.

9.9 Chemical requirements

- **Dissolved solids** influence the taste of water. It is the different substances in true solution in water and may be determined by evaporating clear water in a dish. The dissolved solids will be left after evaporating to dryness and can be weighed.

  The amount of dissolved solids can be roughly calculated (in mg/l) by multiplying the value of electrical conductivity in mS/m by the factor 6,6.

- **Magnesium and sulphate**: these two should be considered together as these ions are normally associated as magnesium sulphate (Epsom salts). Increasing concentrations make the water bitter and cause diarrhoea in man and animal.

- **Sodium and chloride**: these ions are usually bound together as NaCl. Increasing concentrations in water affect the taste and is usually corrosive.

- **Total hardness**: includes both the Calcium and magnesium content of the water and is expressed as mg/l. Ground waters frequently have hardness above 300 mg/l as $CaCO_3$.

  Natural surface waters are usually soft because it does not have much opportunity for contact with minerals. Hardness should be less than 50 mg/l as $CaCO_3$ for effective operation of boilers and laundries:

  - **Minimum value**: too little hardness (especially calcium), can have an adverse effect on babies and growing children's skeletal structure.

    Ca is needed for the growth process for the formation of bones and should be replenished from other sources eg milk, if the concentration is too low. Water, with a low total hardness concentration, is usually corrosive.

- **Maximum value**: as the tota1 hardness increases its scale forming properties also increase. The maximum limit of 300 mg/l. is merely to protect industries, especially hot water systems and boilers from scaling. The limit is not based on any harmful effect on humans.

  Hardness is determined by doing a titration against EDTA solution and the value calculated. If the values obtained from alkalinity and total hardness are approximately the same, the hardness present is mainly temporary hardness.

  A value greater than 200 mg/1 indicates that serious scale formation will occur. If the alkalinity is less than the total hardness, the difference is due to permanent hardness.

  pH of natural water is a function of the total alkalinity and hydrogen ion concentration of the water and varies in the region of 6 - 9 (alkaline). The pH value gives an indication whether water is acidic neutral or alkaline and is measured by means of special indicate; papers, solutions or electronically by a meter.

9.10 Toxic substances

Mainly from industries and to a lesser extend from sewage. Fluoride and nitrate are the only ions mentioned which can naturally occur in water and then mostly in underground water.

- **Nitrate**: is the common form of inorganic nitrogen found dissolved in water. In agricultural areas, groundwater may have a significant concentration of nitrate from unused fertilisers leaking into the underlying aquifers.

  Surface waters can be polluted by discharge of municipal wastewater and drainage from agricultural lands. The heal hazard of ingesting excessive nitrate in water is infant methaemaglobinaemia.

  Nitrate is reduced in the babies (± 3 months) blood, oxidising the iron of hemoglobin. This interferes with oxygen transfer in the blood, resulting in cyanosis, which gives the baby a blue colour.

  This illness is readily diagnosed by a medical doctor and rapidly reversed by injecting methylene blue into the infants' blood. Healthy adults are able to consume large concentrations without adverse effects.

  In certain regions, cattle have died as a result of abnormally high nitrate concentrations (in excess of 100 m/l as N). This occurs after heavy rains when animals drink too much from a riverbed which would normally be dry.

- **Fluoride**: is found in ground waters as a result of dissolution from geological formations. Surface waters usually contain much smaller concentrations.

  Absence or low concentrations of fluoride in drinking water cause the formation of tooth enamel less resistant to decay, resulting in high incidence of dental care in children's teeth.

  Concentrations less than 1 mg/l fluoride have a beneficial effect on bone structure and teeth. More than 10 mg/l will cause knobbly knees in cattle and sheep as a result of sinews which thicken to support the bone which has eroded at that point.

9.11 Bacteriological requirements

If any coliform bacteria are found in a sample, take a second sample immediately. It should be free of coliform bacteria and not more than 5% of the total number of water samples (from any reticulation system) tested per year may contain coliform bacteria.

In addition to bacteria, water may contain other types of undesirable organisms. Micro-organisms are commonly present in surface waters, but usually absent from most ground waters (as are suspended solids) because of the filtering action of aquifers.

The types of micro- organisms that may be found in water are now identified as animals, plants and Protista. The most common micro-organisms are bacteria. Viruses are usually classified separately according to the host they infect.

Bacteria vary in size from about 1 - 4 μ and cannot be seen with the naked eye. Non-pathogenic bacteria are usually harmless. Aerobic bacteria require oxygen for survival; anaerobic bacteria thrive in the absence of oxygen.

Definition:
Pathogens: Disease-causing bacteria.

Facultative bacteria are those who either live with or without 0_2. Eschericia coli (coliforms) are inhabitants of the intestines of warm-blooded animals. These are usually harmless and are taken as an indication that pathogenic bacteria may be present.

Water that has been contaminated recently with wastewater will contain coliform organisms. The presence of coliform organisms in water can be detected by filtering a water sample through a sterile membrane on which the bacteria will be retained.

The membrane is then put in contact with nutrients that will permit the growth of coliform colonies. After a 24 hour incubation period, the colonies can be counted.

9.11.1 Other Micro-organisms

Algae are unicellular plants containing chlorophyl and exist in different forms and sizes in water. They impart taste and odour to water and grow in the presence of sunlight and nutrients in clear streams and ponds.

Excessive algae growth can be controlled by chlorine or copper sulphate and is normally the result of pollution by sewage, fertiliser or effluent from certain industries. Algae can cause problems on a purification plant by causing filters to clog rapidly.

Definition:
Fungi: Plants growing without sunlight that at times will infest water mains, producing unpleasant tastes and odours and even clogging.

Entamoeba hystolitica (one-celled protozoa-animal) is the cause of amoebic dysentery. Crenothrix (iron bacteria) possesses characteristics of larger organisms and thrive in waters containing iron in solution to clog water mains.

They form jelly-like masses which cling to the circumference of wells and pipeline containing little 0_2. It gives rise to unpleasant odours and red-brown water should the iron precipitate.

These organisms can be prevented by removing dissolved iron from the water or maintaining free chlorine residual in the water. If no other choice exists:

1. Obtain the co-operation of the consumers by informing them of the harmless nature of the organisms involved and that their eradication will result in poor quality water for a short period.
2. Add approximately 1 mg/l copper sulphate at the inlet to the distribution network.
3. Organise a program to flush the distribution network by opening the fire hydrants in the system, starting with those nearest to the dosing plant.
4. Thereafter flush the system periodically by opening the hydrants for 24 hours until the entire system has been flushed and all the organisms have been removed. Tell the consumers to do the same. This should preferably coincide with the dry season when gardens need a good watering.
5. Apply this method for approximately one week to ensure that all the micro-organisms are removed and that none remain to create a recurrence of the problem.

Worms can sometimes also be a problem. Usually they are red or greyish in colour. The red worms (bloodworms) are larvae of a certain fly namely the chironomous.

The greyish worms are the larvae of gnats. When a reservoir has openings in it, flies and gnats enter and lay their eggs on the water surface. The larvae hatch attach themselves to the walls, some sink to the bottom of the reservoir.

Ventilators in reservoirs should be provided with a covering of fine gauze. Worms don't give rise to any tastes or smells and are not harmful in any way. As addition of chemicals is ineffective, the only solution is to drain the reservoir and clean it out.

9.11.2 Eutrophication

This is the process whereby water sources become enriched with nutrients that make the water undesirable for human use, both for water supply and recreation.

These nutrients are mainly nitrogen (in the form of ammonia or nitrate) and phosphate. The nutrients originate from fertilisers used for agricultural purposes from to sewage entering a stream.

Visual signs of eutrophication are prolific growth of algae and aquatic plants such as water hyacinths and water lettuce. This in turn leads to a more active food chain. Algae use $C0_2$, inorganic nitrogen, orthophosphate and trace nutrients for growth and reproduction.

These plants serve as food for microscopic organisms. Small fishes feed on these and large fishes consume the small ones. Productivity of the aquatic food chain is keyed to the availability of nitrogen and phosphorous which is often in short supply in natural waters.

The amount of plant growth and normal balance of the food chain are controlled by the limitation of plant nutrients. Abundant nutrients unbalance the normal procession and promote blooms of blue-green algae that are not normally utilised as food by microscopic organisms.

The water thus become turbid due to floating masses of algae which are windblown to the shore where it decomposes and gives rise to bad odours. Decaying algae also settles to the bottom, reducing dissolved 0_2. Certain algae types are known to be responsible for the formation of toxic compounds.

- **Preventing eutrophication**

Macronutrients for plant growth are $C0_2$, inorganic nitrogen and phosphate, and a variety of trace elements such as iron. The key to controlling eutrophication lies in limiting plant nutrients.

Definition:
Macronutrients: A substance required in relatively large amounts by living organisms, in particular.

9.11.3 Temperature stratification and inversion

In the past certain factors were unfortunately neglected in the design of dam outlets to the purification works. In most cases an outlet was provided near the bottom of the dam.

Water withdrawn from this position is usually smelly and may contain iron and manganese in solution. This is the result of temperature stratification and can best be explained by comparing winter conditions with summer conditions.

9.11.4 Winter conditions

During the winter months, water in a deep dam is subjected to reasonable mixing due to cold winds and the fact that the surface water, containing higher oxygen content, is cooled down by the cold atmosphere.

As a result of its high density it will descend to the lower regions of the dam. This creates aerobic conditions throughout the dam. As the temperature of the atmosphere increase during summer, this action is stopped because the warmer, less dense water will remain in the upper portion of the dam.

9.11.5 Summer conditions

Due to warmer water rema1n1ng in the upper layer of the dam, circulation only occurs in the upper 5 - 10 meters and 2 more definite layers form according to their temperature.

Due to changes in the temperature and density of the water, mixing occurs between the upper layer (the epilimnion) and the lower layer (the hypolimnion).

This gives rise to a transient zone known as the thermocline which is usually 1 - 2 meters deep. Conditions in these layers can be summarised as follows:

- **Epilimnion**
  - algae present
  - 0_2 supplied from the atmosphere and algae close to saturation point due to constant circulation
  - Higher temperature due to wind and weather

- **Thermocline**
  - sharp decrease (1 °C or more/meter increased depth) in temperature and 0_2 content.
  - Very little (if any) algae present
  - Usually easiest to purify water from this level

- **Hypolimnion**
  - No dissolved 0_2 present
  - Anaerobic conditions develop due to decaying plants, algae and other organic matter (to form. Soluble organic complexes, largely $C0_2$)

- Low temperature
- Reduced iron and manganese, H_2S and ammonia present
- Bad tastes and odours
- High 0_2 demand
- pH decrease as a result of $C0_2$

Water withdrawn from the hypolimnion contains reduced iron, manganese and hydrogen sulphide which is not only undesirable, but also difficult and costly to treat.

This problem can be overcome by installing a multi-port outlet to withdraw water (of better quality) from a higher level. This also allows for variation in the level of the dam.

It should always be possible to withdraw water from a point less than 5 m from the surface to avoid the hypolimnion. Stratification may be overcome by placing aeration pipes across the bottom of the dam to aerate it.

As soon as the temperature of the atmosphere drops (winter), the water in the upper layers become colder, than in the lower levels, water mlx and conditions will become better.

Activity 9.1

1. Define:
    a) polluted water
    b) methaemoglobinaemia
    c) epilimnion
    d) eutrophication
2. Name three gases which occur in water.
3. Name four suspended impurities in water.
4. Name four properties of water drawn from the bottom of a deep dam.
5. Give four basic requirements with which domestic water should comply.
6. In which units are the following variables expressed:
    a) Colour
    b) Turbidity
    c) Hardness
    d) Conductivity

Self-Check

I am able to:	**Yes**	**No**
• Describe water quality		
• Explain the purpose of water purification		
• Describe the pollution of watersources		
o domestic		
o industrial		
• Describe the impurities found in water		
o suspended matter		
o dissolved solids		
o gases		
• Explain the terminology regarding impurities in water		
• Describe the SABS specifications for domestic water		
o physical requirements		
o chemical requirements		
o toxic substances		
o bacteriological requirements		
• Describe eutrophication		
• Explain temperature stratification and inversion		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 10

Treatment and Units Prior to Filtration

Learning Outcomes
On completion of this module, students should be able to:

- Explain the removal of grit and sand
    - Pre-sedimentation
- Explain the removal of tastes and odours
    - aeration and types of aerators
    - other methods eg chlorine, chlorine dioxide, potassium permanganate, activated carbon
- Describe the removal of algae
    - Pre-chlorination
    - Micro screening
- Describe the removal of iron and manganese
    - Chlorine
    - chlorine dioxide
    - potassium permanganate
    - pH adjustment in conjunction with previous options
- Explain flow measurement and the importance of methods of calculating flow when flow meters are not provided

10.1 Introduction

Treatment prior to filtration is a very important aspect. If pretreatment is not up to standard, it will have an adverse effect on especially the sand filters.

The following pretreatment processes are of importance: removal of grit and sand, tastes and odours, algae, iron and manganese.

10.2 Pre-sedimentation: Removal of grit and sand

Water containing high grit or sand loads is sometimes allowed to settle in dams or tanks prior to chemical treatment.

This is done merely to allow solids to be removed before the water enters the rest of the treatment plant and thereby protecting certain equipment against damage or to prevent blockages caused by sand in the sludge removal system.

10.3 Removal of tastes and odours

Tastes and odours are caused by:

- dissolved gases such as hydrogen sulphide
- living organic material such as algae
- decaying organic material
- industrial wastes
- chlorine either as a residual or in combination with phenol or decomposing organic matter

Aeration, adsorption and oxidation are among the methods that have been used for the removal of tastes and odours.

10.3.1 Aeration and types of aerators

Aeration is used in a variety of operations including the following:

- addition of O_2 to oxidise dissolved iron and manganese
- removal of CO_2
- removal of H_2S to eliminate tastes and odours
- mechanical aerators which promote the mixing of liquid to expose the water to the atmosphere in the form of fine droplets.

Definition:
Aeration: A form of gas transfer.

The particular method used depends on the substance to be removed and the objectives to be achieved. In the different types the aim is to make provision for the maximum interface between air and water to optimise the transfer of the substance to the air.

10.3.2 Other methods

Other methods include the use of chlorine (Cl_2) or ozone (O_3) to oxidise compounds giving rise to tastes and odours or the adsorption of these substances by activated carbon.

Activated carbon also removes residual chlorine and certain organic compounds. The latter is applied for the removal of certain toxic organic compounds such as pesticides.

Chlorine combines with organic compounds such as phenol and may give rise to tastes worse than that of the untreated water whereas ozone does not form such compounds.

Certain chlorinated organic compounds can be successfully removed by the application of excess chlorine or super-chlorination and chlorine compounds such as chlorine dioxide, hypochloride. Potassium permanganate has also been used effectively to oxidise taste-producing matter.

10.4 Removal of algae

Basically two methods can be used to eliminate this problem:

10.4.1 Pre-chlorination

Applied at instances where tastes and odours are to be removed but also for the control of algae. (It should not be employed if floccotan is used as flocculent aid).

10.4.2 Microscreening

A microscreen is a rotating drum covered with fine monofilament plastic mesh. Several grades of mesh are generally used to successfully remove algae and similar contaminants from water where the particle size may be as low as 3 – 5 μm, due to the formation of a thin layer of solids on the inner face of the screen.

Where necessary, backwashing of the screen with spray nozzles is supplemented by the use of ultraviolet irradiation to kill the bacteria and other organic solids. In this way, clogging, due to organic growth, is minimised.

10.5 Removal of iron and manganese

Ferrous iron (Fe^{++}) and manganese (Mn^{++}) are soluble invisible forms that may exist in well waters or anaerobic reservoir water. When exposed to air, oxidising agents such as chlorine, reduce it slowly to transform it to insoluble, visible oxidised ferric ion $(Fe^{++})^{+}$- and manganese (Mn^{++}).

The oxidation rate depends on pH, alkalinity, organic content and presence of oxidising agents. If not removed in treatment, the brown- coloured oxides of iron and manganese create un-aesthetic conditions and may interfere with some water uses.

Preventive measures may sometimes be used with reasonable success. Addition of sodium hexametaphosphate, while not preventing oxidation of metal ions, may keep them in suspension and thus moving through the system without creating accumulations that periodically cause badly discoloured water.

Reduced iron in water promotes the growth of autotrophic bacteria in distribution mains. Periodic flushing of small distribution pipes may be effective in removing accumulations of rust particles; however, elimination of iron bacteria is generally difficult and expensive.

Biological growths are particularly obnoxious when they decompose in the piping system, releasing foul tastes and odours. Heavy chlorination of isolated sections of water mains followed by flushing has been effective in some cases.

The only permanent solution to iron and manganese problems is by removal by water treatment. The SABS specifications (241 of 1984) recommends a maximum of 0,1 mg/l for iron and 0,05 mg/l for manganese.

The problems arise when iron or manganese is in its lower oxidation state and in solution; it therefore passes through the filters. When chlorine is added, it is oxidised to a higher oxidation state and precipitates.

The manganese forms a fine black precipitate and the iron a red- brown precipitate. This precipitate may settle in the reservoir or in pipelines and may result in slugs of high concentrations when disturbed.

Iron and manganese can be found in water extracted near the bottom of deep dams due to temperature stratification. High concentrations can also occur in borehole water, especially if it is situated near a mountainous region and the water has a low dissolved mineral content but contains dissolved CO_2.

The most important characteristic of both surface and borehole water which contains iron and/or manganese in solution is that such water is normally very soft and therefore corrosive.

Manganese removal is more complicated and difficult than iron removal. Among methods used for the removal of iron and manganese are:

a) Aeration
b) Oxidation with chlorine
c) Potassium permanganate
d) pH adjustment in combination with previous options
e) ion exchange, etc.

Oxidation and precipitation are the most commonly used methods.

10.5.1 Aeration

In natural waters, iron is normally found as ferrous bicarbonate $(Fe(HCO_3)_2$. This compound is unstable and precipitate easily when in contact with O_2 to form ferric oxide. The reaction is as follows:

$$4\,Fe(HCO_3)_2 + O_2 + H_2O \rightarrow 4\,Fe(OH)_3 \downarrow + 8\,CO_2$$

According to the reaction, iron in the ferrous forms is oxidised to insoluble ferric hydroxide which can be removed as a precipitate. If the iron content is not high, the resulting precipitate can be removed by filtration. The CO_2 content which is set free is neutralised by adding slaked lime.

Depending on the CO_2 concentration, which in turn depends on the ferrous bicarbonate present in water, a white precipitate of $CaCO_3$ will occur while some $CaHCO_3$ will go into solution.

Organic iron compounds will not be eliminated by aeration. This method will also not be used when problems exist with hard water. Manganese is very difficult to remove and plain aeration is generally ineffective.

The simplest form of oxidation in treatment of well water is as follows: a typical tray-type aerator has a vertical riser pipe that distributes water on top of a series of trays from which it then drops and splatters down through the stack.

The trays frequently contain coke or stone contact beds that develop and support oxide coating speeding up the oxidation process.

10.5.2 Lime treatment

As in the abovementioned reaction, ferrous bicarbonate can be precipitated by adding slaked lime. A deposit of ferric hydroxide and calcium carbonate results:

$$4\,Fe(HCO_3)_2 + 8\,Ca(OH)_2 \rightarrow Fe(OH)_3 \downarrow + 8\,CaCO_3 + 6\,H_2O + O_2$$

The ferric hydroxide and calcium carbonate formed is removed by sedimentation and filtration. It may be necessary to add a flocculent to improve sedimentation.

Increasing the pH to about 8,5 with lime or soda ash enhances the oxidation of manganese which will then precipitate together with $CaCO_3$. The only disadvantage of this method is that pH correction is necessary and CO_2 must be added which increases costs.

Definition:
pH: A figure expressing the acidity or alkalinity of a solution on a logarithmic scale on which 7 is neutral, lower values are more acid, and higher values are more alkaline.

10.5.3 Oxidation with chlorine

If the dissolved oxygen concentration is low, the chlorine demand of the water will be proportionately higher and large quantities will have to be dosed before the iron is oxidised.

Substances such as H_2S also increase the chlorine demand. Another factor to consider before using this method is the cost of installing chlorine apparatus.

Oxidation of manganese with chlorine is very successful. Pre-chlorination is applied and the black precipitate is removed by adding a flocculent. It is important to have not less than 0,4 mg/ l free available chlorine during the sedimentation and filtration period.

10.5.4 Oxidation with potassium permanganate

This method is more effective than chlorine. Enough potassium permanganate and a contact time of ± 5 - 20 minutes is necessary for efficiency of the process.

The following is a common sequence of processes for removing iron and manganese:

- Preliminary aeration strips dissolved gases and adds O_2.
- Iron and manganese are chemically oxidised by free chlorine residual or potassium permanganate at rates higher than with dissolved oxygen. When chlorine is used, a free residual is maintained throughout the treatment process. The specific dosage required depends on the concentration of metal ions, pH, mixing conditions and other factors. Permanganate oxidation may be advantageous for certain waters, since the rate of reaction is relatively independent of pH.
- Effective filtration following chemical oxidation is essential, since a significant amount of the flocculent metal oxides are not heavy enough to settle by gravity.

Iron and manganese, carried over to the filter, coat the media with oxides that enhance filtration removal. Practice has shown that new filters pass manganese until the grains are covered with oxides that develop naturally during filtration of manganese- bearing water.

Inefficient removal of manganese can cause serious problems with post-chlorination for establishing a residual in the distribution system.

Manganese not taken out by the aeration - filtration process may be oxidised in the injector mechanism of the solution - feed chlorinator and may clog the unit, or in the distributing piping, the oxidising effect of the residual chlorine may create staining water.

Iron and manganese can also be precipitated by the oxidative action of ozone. Ozone breaks up the complexes at neutral pH, whereas without ozonation pH values greater than 9 have to be adjusted.

10.6 Flow measurement

Measurement of flow is essential to determine:

- at what concentrations chemicals are dosed;
- water losses through the plant and distribution system by metering water delivered against inflow;
- unit costs of treated water;
- retention times through various units;
- changes in water delivery due to factors such as drop in efficiency of pumps, deterioration of pipelines, blockages, leakages, etc.

Activity 10.1

1. Which methods are used to remove iron and manganese on a conventional water treatment plant?
2. Why should iron and manganese be removed?
3. According to SABS 241 of 1984, what is the recommended limit and units for iron and manganese?
4. What is meant by:
   a) Pre-sedimentation
   b) Pre-chlorination
   c) Aeration
5. Give the names of the following compounds:

   $Ca(OH)_2$; $CaCO_3$; $KMnO_4$; $Mn(HCO_3)_2$; $Fe(HCO_3)_2$; $Fe(OH)_3 \downarrow$;
   Fe^{++}; MnO_2; $Ca(OC1)_2$.

Self-Check

I am able to:	**Yes**	**No**
• Explain the removal of grit and sand		
o Pre-sedimentation		
• Explain the removal of tastes and odours		
o aeration and types of aerators		
o other methods eg chlorine, chlorine dioxide, potassium permanganate, activated carbon		
• Describe the removal of algae		
o Pre-chlorination		
o Micro screening		
• Describe the removal of iron and manganese		
o Chlorine		
o chlorine dioxide		
o potassium permanganate		
o pH adjustment in conjunction with previous options		
• Explain flow measurement and the importance of methods of calculating flow when flow meters are not provided		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 11

Flocculation

Learning Outcomes

On completion of this module, students should be able to:

- Describe destabilisation of colloidal particles
- Describe the following processes:
  - flash mixing
  - floc formation
  - floc conditioning
- Describe flocculants and flocculant aids:
  - optimum floc and pH adjustment
  - Aluminium sulphate - amphoteric properties, optimum pH range for aluminium hydroxide
  - Ferric chloride - optimum pH range for ferric hydroxide
  - Ferrous sulphate, ferrous salts (under special conditions), floccotan, sodium aluminate, synthetic polyelectrolytes (anionic, cationic and non-ionic), lime, sodium carbonate, acids, activated silica, bentonite and other clays, precipitated calcium carbonate
- Describe excess lime treatment for flocculation of hard waters followed by recarbonation
- Reasons for post precipitation
- Dosing equipment
  - liquids, solids followed by solutionising
  - calibration of dosing equipment
  - control of dosing rates
- Describe laboratory jar tests (theory only)
- Apply laboratory jar test results and set dosing equipment
- Maintain records

11.1 Introduction

This module deals with the first step in the clarification process namely flocculation.

It is important to know the different flocculants and -aids, different dosing methods used, theory of laboratory jar tests and application of the jar tests

results.
Students should also be able to calculate dosages and costs for treating water.

11.2 Destabilisation of colloidal particles

To clarify water, suspended matter must be removed by settling with the aid of a flocculent. Suspended matter vary in size from coarse material which will settle out on its own, to fine colloids unable to settle unless a flocculent is added.

The objective of chemical dosing is to cause individual fine particles to agglomerate into larger ones. The specific chemicals applied in coagulation for turbidity removal depend on the character of water and economic considerations.

Colloids carry similar electrical charge, normally negative. This causes the particles to repel each other. The charge should thus be neutralised by adding a positive charge (chemicals).

Through this action the negative charges are neutralised so that the colloids combine to form larger and heavier particles able to settle out.

11.3 The process

The process consists of three successive steps:

11.3.1 Flash mixing

Even distribution of flocculent throughout the whole volume of water in less than one second. The amount added should just be sufficient to neutralise the charge of all the colloids present.

Neutralisation only occurs in the region of the flocculent and therefore the water and flocculent should be thoroughly mixed.

Optimum conditions can be determined by doing a jar test. Flocculent should be added at points of maximum turbulence, for example where water flows.

11.3.2 Floc formation

Physical and chemical changes take place in the formation of fine floes which are still too small to settle on their own.

11.3.3 Floc conditioning

Conditions are created where the fine floccules collide and adhere to each other. The water should be agitated slowly to enable the particles to collide to form bigger and heavier floccules.

The time needed to produce a heavy and well-formed floc will mainly depend on the temperature of the water.
The lower the temperature, the slower the flocs will form and the higher the temperature, the easier and faster the floc will form. Properly formed floes should be dense rather than feathery.

11.4 Flocculants and flocculant aids

Flocculants are used as an aid to clarify water in the sedimentation and filtration processes.

11.4.1 Aluminium Sulphate

This is the most popular and most frequently used flocculant. Good results are obtained with most types of water.

- Alum is supplied in different forms: in cobbles, granular or powder forms, usually in 50 kg bags.
- Pure aluminium sulphate consists of white crystals bound to 18 molecules of water of crystallisation. Commercial alum is yellow-brown (because of iron impurities) and contains 14 molecules of water of crystallisation. $(Al_2(SO_4)_3.14H_20)$.
- When alum is dissolved in water, sulphuric acid (H_2SO_4) is formed which will lower the pH. The final pH reached will depend on the amount of aluminium sulphate needed. If necessary, lime or soda ash could be used for final adjustment of pH.

$$Al_2\,(SO_4)_3\,.14H_2O - H_2O \rightarrow 2Al^{3+} + 3SO_4 = +15H_2O$$

$$SO_4 = +H_2O \rightarrow H_2SO_4\,(sulphuric\ acid)$$

- The aluminium cations react with the hydroxyl anions in water in the pH range, 6,0 - 7,5.
- The solution tank, pipes and pumps should be corrosion resistant and preferably made of plastic or glass fibre.

11.4.2 Ferric chloride

- Available in solid form, but normally supplied as a 43% (m/m) solution.
- Ferric chloride is yellow- brown and is sold in 20 or 200 litre containers.
- Due to the formation of HCl in water, it is more corrosive towards metals, even stainless steel and any nylon type plastics, than alum. Only plastic material and dosing equipment resistant to ferric chloride may be used.

$$FeCl_3 + H_20 \rightarrow Fe^{3+} + 3Cl^- + H_2O$$
$$Cl^- + H_2O \rightarrow HCl\,(Hydrochloric\ acid)$$

- The pH range for effective flocculation is ± pH 5 to pH 14.

- If necessary lime or soda ash could be used for final adjustment and may be added before or with the addition of ferric chloride.
- More economical to use alkalinities are treated than alum when waters with high alkalinities are treated. The reaction is as follows:

$$2\,FeCl_3\ -\ 3\,Ca(HCO_3)_2 \rightarrow\ 2\,Fe(OH)_3 \downarrow + 3\,CaCl_2 \downarrow - 6\,CO_2$$

pH will drop due to $C0_2$ in water, but can be neutralised by addition of lime.

- Ferric chloride forms a heavier floc than alum and thus settles more quickly.

11.4.3 Ferric sulphate

- Ferric sulphate crystals do not dissolve easily and require hot water for dissolution.
- When dissolved, sulphuric acid is formed which lowers the pH.
- Alkalinity changes quicker with ferric sulphate than with ferric chloride.
- When added to water with natural alkalinity, the following occurs:

$$Fe_2(SO_4)_3\ +\ 3Ca(HCO_3)_2\ -\ 2\,Fe(OH)_3\ +\ 3\,CaS0_4 +\ 6\,C0_2$$

pH is lowered due to $C0_2$ and must be neutralised by the addition of lime.

- Ferric sulphate flocculates over a large pH range.

11.4.4 Ferrous salts

- Sometimes used to aid in phosphate removal.
- Ferrous sulphate forms sulphuric acid when dissolved.
- High alkalinity is needed to oxidise ferrous ions to the ferric state.
- pH must be 8,5 or higher for complete precipitation of ferric hydroxide.
- Addition of lime is normally necessary.

11.4.5 Sodium aluminates

Can be used as either a coagulant or coagulant aid.

11.4.6 Floccotan

- Brown organic liquid made from wattlebark extract.
- Sometimes preserved by the addition of an acid or mixed with polyelectrolytes.
- pH of untreated water unaffected at normal dosages and it is not corrosive.
- Floccules which forms settles reasonably quickly.
- Lime or soda ash is only necessary for stabilisation of water. It can be added before or with the floccotan.
- Should not be stored for more than six months.
- Cannot be used when pre-chlorination is practised.

- If it is to be used with ferric chloride or alum, never mix the solutions in the same container.
- Because of its organic origin, it serves as a nutrient for certain slime forming organisms which adversely affect filter runs.

11.4.7 Polyelectrolytes

There are various types used as flocculant aids. A heavier and better formed floc is usually obtained. These products is however very expensive and should not be used without expert advice.

11.4.8 Lime, sodium carbonate

- Slaked lime and sodium carbonate (both alkalis) are generally used for pH or stabilisation control. Under special conditions it can however be used as flocculant, especially when treating water high in both temporary and permanent hardness.
- Slaked lime ($Ca(OH)_2$) and sodium carbonate (Na_2CO_3) (also called soda ash) are available in powder form and are usually white in colour.
- Lime is dosed in a slurry or suspension and must be kept in even suspension by means of a stirrer to enable dosage at a constant rate.
- Not severely corrosive towards metals.

11.4.9 Activated silica

Give good results when used with alum.

11.4.10 Bentonite and other clays

Bentonite and kieselguhr are used when raw water has a low turbidity in order to weight the floc formed by the flocculant and are known as weighing agents.

11.4.11 Precipitated calcium carbonate

Ideal flocculant aid which can be used the same way as clays, together with another flocculant. When treating soft water in a sludge blanket type of sedimentation tank, it reduces or eliminates the corrosive properties of water.

Excess $C0_2$ in water reacts with $CaCO_3$ to dissolve some of it. Little or no lime is needed for pH correction.

11.5 Excess lime process

The process is more economical when slaked lime is produced on site by burning limestone in kilns.

$$CaCO3 \xrightarrow{\text{heat}} CaO + CO2$$

(Limestone) (Calcium oxide)

Lime is slaked.

The calcium oxide (unslaked lime) is treated with water to form slaked lime $(CaOH)_2$.
$CaO + H_2O \rightarrow Ca(OH)_2 \downarrow$

11.5.1 Temporary hardness

When water is high in both temporary and permanent hardness, it is treated with an excess of slaked lime to obtain a pH of 11,0.

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2\,CaCO_3 \downarrow + 2\,H_2O$$

$CaCO_3$ is insoluble crystals (limestone) which can be removed.

pH less than 11,0

$$Mg(HCO_3)_2 + Ca(OH)_2 \rightarrow MGCO_3 + CaCO_3 \downarrow + 2\,H_2O$$

pH higher than 11,0

$$MgCO_3 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaCO_3 \downarrow$$

$CaCO_3$ crystals are absorbed into the floc during the conditioning process and serve to weight the floc making it to settle more quickly.

11.5.2 Permanent hardness

$Mg(OH)_2$ also forms when $MgSO_4$ (permanent hardness) is present. Softening is not achieved because the magnesium ions are exchanged for calcium ions to form $CaSO_4$ (gypsum).

$$MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 \downarrow CaSO_4$$

An advantage of the high pH (due to $Mg(OH)_2$) is that most bacteria in water will be destroyed. After pre-sedimentation, the relatively clear effluent still containing an excess of lime in solution, must undergo re-carbonation (secondary treatment).

The excess $Ca\,(OH)_2$ is neutralised by bubbling CO_2 (from burning limestone) through water. $CaCO_3$ crystals precipitate and $CaHC0_3$ pass into solution to help control the saturation index of water.

11.6 Reasons for post-precipitation

Some of the fine $CaCO_3$crystals formed do not settle out easily their own and need the addition of a flocculant. Ferric chloride gives best results. The same conditioning is necessary as for the primary sedimentation process and a second series of sedimentation tanks is thus necessary.

The secondary sedimentation process can sometimes be eliminated by adding an excess of CO_2 to convert $Ca\,(OH)_2$ to soluble $Ca(HC0_3)_2$.

11.7 Dosing equipment

There are two different methods of dosing chemicals:

- liquids
- solids followed by solutionising

It is important not to feed flocculants in dry form into the raw water.

11.7.1 Solutions

A container IS necessary for the solutionising and it is then dosed through a constant head feeder, piston pump, diaphragm pump or any other positive displacement pump.

If lime is used, a stirrer is necessary in the container to keep an even suspension. In this case a small centrifugal or mono pump is the most suitable.

The container should be able to hold solution for at least eight hours. A second tank is advisable to ensure continuation of the process.

11.7.2 Dry feeders

These feeders are equipped with a hopper and interconnected feeder. The feeder functions by means of a conveyor belt; a wormscrew, slowly rotating disc, etc.

It is important to determine exactly how much the feeder delivers when set to various calibration marks. The dry flocculant is then solutionised and flows onto the dosing point.

Sufficient water and time should be alloced for complete solutionising. An electric stirrer can be of great help. The containers and stirrers should be acid resistant.

11.8 Laboratory jar tests

Jar tests are done to determine the most economical amount of floc to be added to the raw water for optimum clarification. Efficient coagulation and flocculation is influenced by the following factors:

- temperature
- turbidity
- colour
- pH
- alkalinity
- time and effectiveness of mixing
- agitation during floc formation
- characteristics of coagulants being used
- hydraulic conditions during flocculation

Jar tests are done when:

- new water sources are developed
- when sudden changes occur in quality of existing water sources

The tests are done as follows:

- One would normally start with alum and lime as these are the most generally used flocculants.

11.8.1 Sampling

A representative sample for four series of jar tests should be taken. The period over which the tests are carried out should be quick so as to prevent a rise in temperature. Determine pH, colour and turbidity of raw water. F

ilter the water through filter paper and determine the colour and turbidity again. Place the six samples in the beakers, add required flocculant/s to each beaker, stir for 2 minutes at 100 r/min and at 40 r/min for 8 minutes.

Record the nature of floc formed. Switch the stirrers off and allow to settle for 10 minutes. Determine the colour and turbidity of the super natent and also of the filtered water. Determine the pH of each sample.

Figure 11.2 Laboratory jar stirrer

11.8.2 Application of jar test results

Once the optimum dosage has been determined in the laboratory, it must be applied on the plant. In the laboratory the dose is determined according to the standard method and expressed as mg/l when this is applied to the plant, the method used is to convert all units to the same group:

$$Mg/l \;=\; g/m^3 \;=\; kg/Ml$$

This can be applied as follows:

Worked Example 11.1

The optimum dose determined by the jar test is 20 mg/l. The flow through the plant is $30\,m^3/min$. What will the dosage be?

$$20\,mg/l \;=\; 20\,g/m^3$$

$$\begin{aligned} Chemicals\ needed \;&=\; Dosage \times flow \\ &=\; 20\,g/m^3\ x\ 30\,m^3(min \\ &=\; \frac{600\,g}{min} \\ &=\; 600\,g\ per\ minute \end{aligned}$$

This means that the dry feeder must be set to deliver 600 g/min.

Worked Example 11.2

At the end of the day, 880 kg Alum was used to treat 43,4 Ml of water. Calculate the dosage in mg/l.

$$\begin{aligned} Dosage \;&=\; \frac{Chemicals\ used}{flow} \\ &=\; \frac{880\,kg}{43{,}4\,Ml} \\ &=\; 20{,}27\,kg/Ml \\ &=\; 20{,}27\,mg/l \end{aligned}$$

This means that the dosing for the day is acceptable in relation to the 20 mg/l determined in the laboratory.

Worked Example 11.3

The optimum dosage is 20 mg/l. It is expected that 18 000 000 m^3 water will be treated during the year. Alum costs 8 c/kg. Calculate how much should be budgeted for the year.

$$Alum\ dosage\colon\ 20\,mg/l \;=\; 20\,kg/Ml$$

$Water\ to\ be\ treated: 18\,000\,000\ m^3\ =\ 18\,000\ Ml$

$Total\ chemicals\ needed$

$= 20\ kg/Ml\ \times\ 18\,000\ Ml$
$= 360\,000\ kg$
$= 360\ tons$

$Cost: 8\ c/kg\ =\ R80\ per\ ton$
$\therefore\ 360\ \times\ R80$
$= R28\,800{,}00\ /year$

Worked Example 11.4

If the capacity of the plant is 4 500 m^3/d, with an optimum dosage of 45 mg/l, calculate the number of full bags of alum to be dissolved in 2 containers and the size of the containers if it is to last for approximately 12 hours.

Quantity of alum needed per day:

$$
\begin{aligned}
45\ mg/f\ &=\ 45\ kg/Ml\ -\ 45\ g/m^3 \\
&= Dosage\ \times\ flow \\
&= 45\ gm^3\ \times\ 4\,500\ m^3/\ d \\
&= 202\,500\ g/d \\
&= 202{,}5\ kg/d
\end{aligned}
$$

∴ 4 x 50 kg bags are needed per day, thus 2 bags per container.

If a 10% solution is required, the containers should be approximately 1 m^3 in capacity. Dissolve 2 x 50 kg bags of alum and make up to 1 m^3 with water.

The volume of solution to be dosed:

1 m^3 solution must be dosed in 12 hours

$$
\begin{aligned}
ml/min\ &=\ \frac{1\,000\,000}{12\ \times 60} \\
&= 1\,389\ ml\ solution\ per\ minute
\end{aligned}
$$

It can also be calculated by the following formula:

$$C_1V_1\ =\ C_2V_2$$

Where: C$_1$ = concentration of alum (kg/m^3)

V_1 = volume alum to be dosed per minute (ml)
C_2 = optimum dosing desired (g/m^3)
V_2 = flow of raw water (l/min)

$$V1 = \frac{C_2V_2}{C_1} \qquad 4\,500\ m^3/d$$
$$= \frac{45\ g/m^3 \times\ 3\,125\ l/min}{100\ kg/m^3}$$
$$= 1\,406\ ml/min$$

Dosing equipment should be set according to jar test results and calculations for optimum clarification.

Worked Example 11.5

A tank with capacity 20 m^3 is given. Prepare a 10% solution (m/m) is this tank. How much chemicals would you need to prepare this solution?

$$Chemicals\ needed\ = \%\ solution\ x\ volume\ of\ tank$$
$$= 10\% \times 20\,000\ kg\ (1l\ =\ 1\ kg)$$
$$= 2\,000\ kg$$

Raw water is pumped to a works at 65 m^3/l. The above solution must be dosed at 100 mg/l. At what rate (seconds/litre) must the solution be dosed?

$$Dosage\ rate\ = \frac{864\ \times\ \%\ solution\ \times\ relative\ density}{flow\ in \frac{ml}{d} \times\ dosage}$$
$$= \frac{864\ \times\ 10\ \times\ 1}{1{,}56 \frac{ml}{d} \times\ 100\ mg/l}$$
$$= \frac{8\,640}{156}$$
$$= 55{,}4\ seconds/litre$$

(864 = constant value to convert 24 hours to seconds)

Take Relative density as 1
65m^3/h =
= 1 560 m^3/d
= 1,56 ml/d

Activity 11.1

1. Define: a) temporary hardness b) permanent hardness
2. The optimum dosage is 25 mg/l. It is expected that 14 000 000 kl of water will be treated during the year. How much alum will be used for this time period?
3. Give the reaction when limestone is burnt.
4. What is the purpose of jar tests?
5. Discuss in short the influence of mixing on flocculation.

Self-Check

I am able to:	**Yes**	**No**
• Describe destabilisation of colloidal particles		
• Describe the following processes:		
o flash mixing		
o floc formation		
o floc conditioning		
• Describe flocculants and flocculant aids:		
o optimum floc and pH adjustment		
o Aluminium sulphate - amphoteric properties, optimum pH range for aluminium hydroxide		
o Ferric chloride - optimum pH range for ferric hydroxide		
o Ferrous sulphate, ferrous salts (under special conditions), floccotan, sodium aluminate, synthetic polyelectrolytes (anionic, cationic and non-ionic), lime, sodium carbonate, acids, activated silica, bentonite and other clays, precipitated calcium carbonate		
• Describe excess lime treatment for flocculation of hard waters followed by recarbonation		
• Reasons for post precipitation		
• Dosing equipment		
o liquids, solids followed by solutionising		
o calibration of dosing equipment		
o control of dosing rates		
• Describe laboratory jar tests (theory only)		
• Apply laboratory jar test results and set dosing equipment		
• Maintain records		

If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

Module 12

Sedimentation

Learning Outcomes

On completion of this module, students should be able to:

- Explain the principles of sedimentation
    - Factors affecting the process - size, temperature and viscosity of water, depth, surface area, inlet and outlet flow rate
- Identify common problems
    - Short circuiting
    - eddy currents
    - convection currents
    - wind action
    - algae
- Identify and describe types of tanks
    - Fill and draw
    - horizontal flow
    - vertical flow with sludge blankets
    - vertical flow without sludge blanket
    - radial flow tanks
- Perform the following calculations:
    - Nominal or theoretical retention time
    - % efficiency of retention
    - upward flow velocity
    - weir overflow rate
- Describe sludge draw-off
- Demonstrate maintaining control and records

12.1 Introduction

This module deals with the second step in the clarification process, namely sedimentation.

On completion of this module you should understand the principles of sedimentation and the factors affecting it. You should understand common problems encountered.

You should also know and be able to draw the different types of sedimentation tanks and be able to do calculations regarding retention time, efficiency of retention, upward flow velocity and weir overflow rate.

12.2 Principals of sedimentation

The sedimentation/clarification process consists of the removal, under gravitational force, of particulate chemical floc and precipitates from suspension, with a density greater than that of water.

The purpose of the process is to remove as much colloidal and suspended matter as possible and so lessen the load on the sand filters. Sedimentation occurs naturally in dams and lakes, but at the waterworks, ideal conditions must be created for it, with sludge removal also provided.

12.2.1 Factors affecting sedimentation

The settling rate of a particle in water depends on the following:

a) *The temperature* and thus the *viscosity* of the water. Warm water is less viscous and a particle will settle more rapidly than in cold water.
b) *The size, shape and specific gravity of the particle:* bigger, rounder and heavier particles settle more quickly. The size of a floc is not necessarily an indication of its weight. Large floes are normally light and feathery and filled with water and settle slower than small dense floes.
c) *Surface area of the tank:* the larger it is, the slower the upward flow velocity and the quicker the floc settles.
d) *Effective depth of the tank:* it must be deep enough to be able to store sludge.
e) *Effective retention time* must be long enough to allow floc particles to settle.
f) *The rate of flow* through the tank must be fairly slow.
g) *Design of inlet and outlet:* the inlet should allow smooth entry. Turbulence can be eliminated by adding baffles at the point of entrance. The outer design is very important. The weir length and uniformity of overflow are important. Water should overflow evenly at not more than 10 m3/h/m length of weir.
h) *Overflow rate or upward flow velocity:* is the rate at which water in the tank rises at normal flow rate. As long as the settling rate of floccules is greater than the upward flow rate, the floc will settle. Normal upflow rate is ± 1 m/hour. Higher upflow rates need excessive flocculants and lead to shorter filter runs. Upflow velocity can also be expressed as $m^3/m^2/h$.

12.3 Common problems

Flow should be evenly distributed across the inlet of the basin. If currents permit a substantial portion of the water to pass directly through the basin without being retained for the intended time, the flow is said to be "short circuiting".

Properly located baffles near the entrance to the basin will distribute the flow, reduce turbulence and reduce dead space in the basin.

Temperature changes as little as 0,5 °C can cause convection currents with resulting carry-over of excessive quantities of floc to the filters and their premature clogging.

A sudden increase in mineral content of the raw water by about 1 000 mg/l and therefore an increase in density will have the same effect.

Wind action can also seriously disturb tank operation and lead to sludge carry-over. Excessive algae growth may be controlled by application of copper sulphate.

12.4 Types of sedimentation tanks

12.4.1 Fill-and-draw tanks

Mainly used for small communities of about 200 persons, see **Figure 12.1**. Two tanks are needed with drainage facilities for cleaning purposes. Flocculant is added continuously and mixed with the incoming raw water until the tank is filled.

Leave the flocculated water at least overnight to allow floc to settle. Usually a very clear effluent is obtained which is passed through a sand filter and chlorinated while another tank is filled with water.

Advantages:

- They can be cleaned on a more regular basis than a conventional sedimentation tank.
- For small communities, conventional sedimentation tanks will not be able to operate continuously, as the flow is too little.

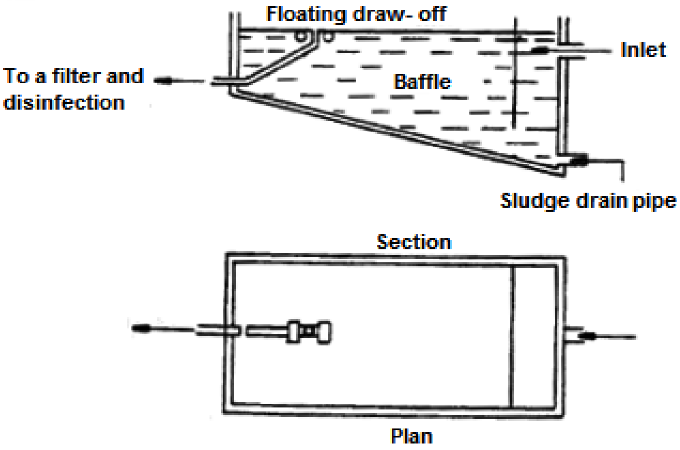


Figure 12.1 Fill and draw sedimentation tank

12.4.2 Horizontal flow sedimentation tanks

The tank is designed with an inlet at the one end and an outlet on the other end, see **Figure 12.2**. It covers a large area and is of heavy concrete construction.

The area required for sedimentation in m^2, must be at least once or twice that of the hourly flow rate in m^3. Baffles are placed at the inlet and outlet weirs.

A baffled canal consists of a concrete tank with baffles around which the water must flow in its path through the tank. The baffles near the inlet are close together, the distance between baffles increases towards the outlet.

The purpose of this is to let the flow velocity of the water gradually decrease. As the water flows around the baffle, vortexes and turbulence occur. This enables the floc particles to collide with each other.

As the water progresses through the canal the turbulence decrease and the chance of the floc breaking up is minimised. A baffled canal gives the best results at or near its designed flow rate. If the flow is too low some of the floc will already settle here.

When the flow through the works must be decreased, it is better to use fewer sedimentation tanks. The tank must be emptied from time to time to remove sludge deposits from the sides.

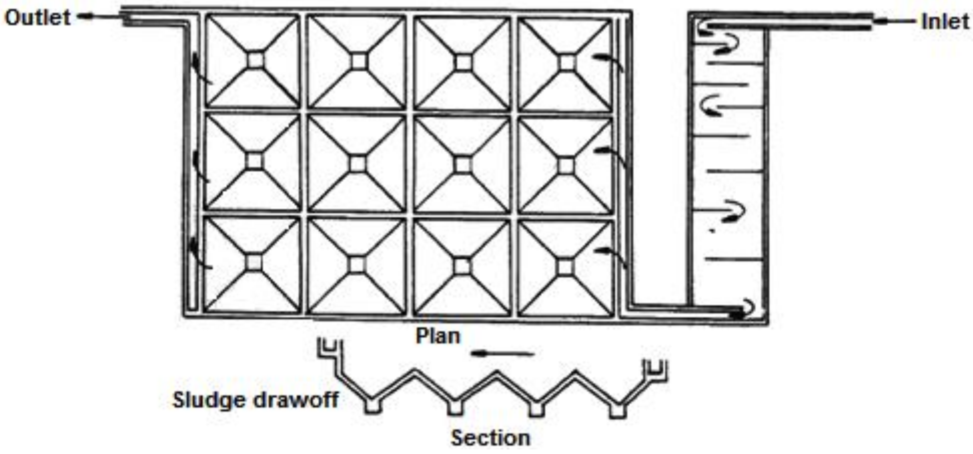


Figure 12.2 Horizontal flow sedimentation tank with baffled canal

12.5 Vertical flow sedimentation tank

12.5.1 Without sludge blanket

This type is similar to a sewage clarifier with inlet into a central flocculating chamber. The water flows downward out of the chamber and then flows upwards and radially outwards to the peripheral weir.

Sometimes the weir length is extended by placing "spokes" from centre to outer weir to act as additional collectors.

Conditioning takes place in the bottom of the tank where the flow velocity gradually decreases. Sludge is concentrated in the lower part of the tank and removed periodically.

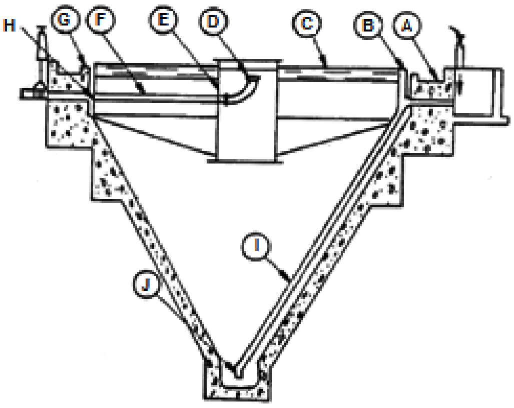


Figure 12.3 Vertical flow sedimentation tank without sludge blanket

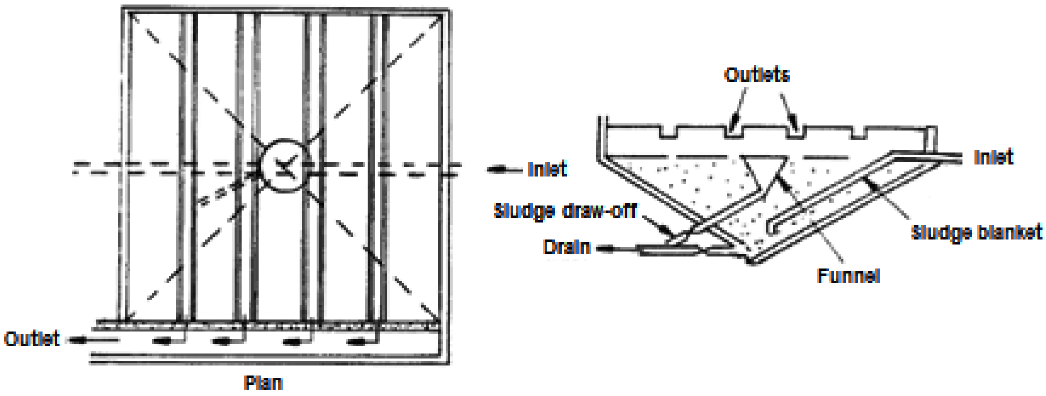


Figure 12.4 Vertical flow sedimentation tank with sludge blanket

Due to the high velocity at the inlet pipe to these tanks, it is inadvisable to have already formed floc in the pipeline as it will be broken on entering the tank.

Conditioning takes place in the bottom of the tank where the flow velocity gradually decreases as in the baffled canal. Floc is allowed to build up to form a sludge blanket.

Old floc serves as a nucleus around which the new floc can attach itself. Partial filtration of the floc occurs as the water and floc particles move upwards.

The sludge concentration increases as the upflow velocity decreases, until it reaches its highest concentration near the top where the upflow velocity remains constant.

Problems can be expected with the removal of sludge: if the sludge concentration is too low, water losses can be high. Best results are obtained when a large plastic funnel is installed in the upper region of the sludge blanket.

The depth of the sludge blanket can be controlled as the excess sludge flows into the funnel where it concentrates and can be removed when the funnel becomes full.

The pulsator clarifier makes use of a sludge blanket and a vacuum device which cause intermittent rise and fall of the sludge blanket in order to minimize short circuiting and also to aid in the compaction of sludge.

Once the floc has been added, the water flows into the tank where it is conditioned by the sludge blanket. The flow is not steady but has a pulsating action.

During the first half of the cycle (**Figure 12.5**(below)) the air valve (V) connecting the vacuum chamber to the atmosphere is closed and the water rises in the vacuum chamber (A).

The water enters the clarifier (D) at a reduced flow rate and the sludge settles in the sludge blanket and in the concentrator (C). During the second half cycle (**Figure 12.5**(on the following page)) the water in the vacuum chamber reaches the level of the top electrodes (S) and the aid valve opens.

The water in the vacuum chamber A enters the sludge blanket, which rises with the water and the excess sludge enters the concentrator C while the clarified water flows off at E.

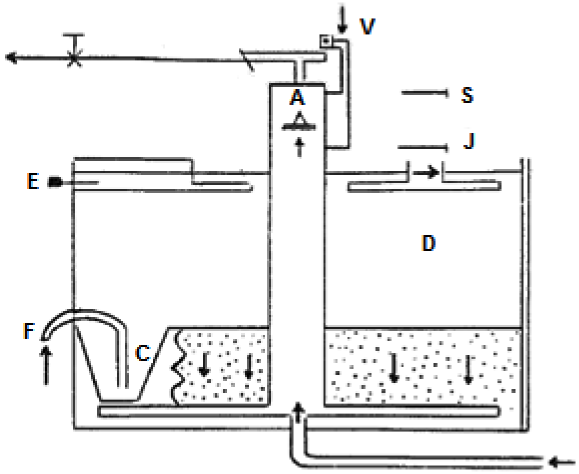


Figure 12.5

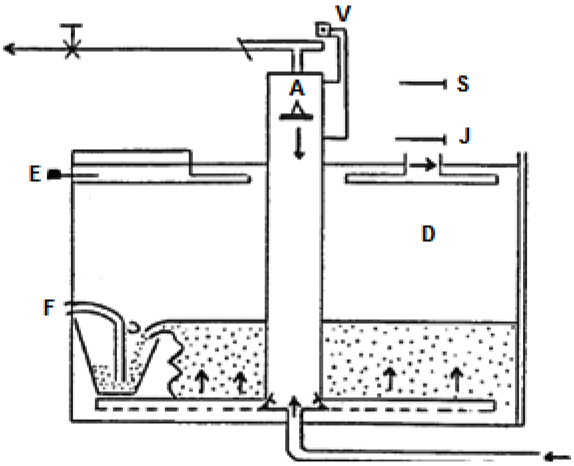


Figure 12.5 Continued

When the water falls to the level of the bottom electrode I, in the vacuum chamber A, the valve V closes. The compacted sludge in the concentrator C is removed via automatic valve F.

12.6 Radial flow sedimentation tank

Flash mixing is usually done outside the tank, see **Figure 12.6**. The inlet and conditioning zone is in the centre, conditioning is aided by electrically driven mixers.

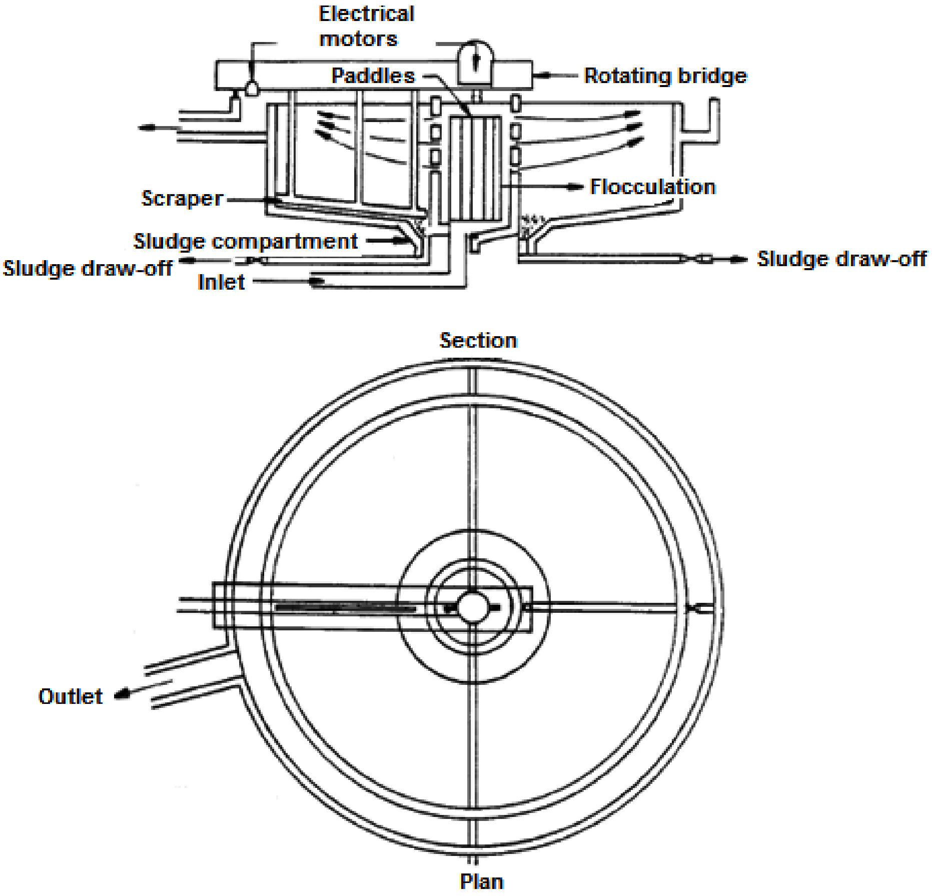


Figure 12.6 Radial flow sedimentation tank

Most of these tanks have nearly flat bottoms, with a slight fall to the middle. Scrapers are used to scrape the settled sludge on the bottom to a sludge hopper and is removed regularly by means of a pipe.

The flow velocity of the water leaving the flocculation compartment is highest at the point just outside the compartment and gradually decreases to the side, allowing the floc particles to settle.

12.7 Calculations

12.7.1 Nominal or theoretical retention time

Retention time of a tank or container is the time needed to fill the tank or container with water flawing in at a constant rate. It can be expressed as follows:

Theoretical retention time (nominal through flow time)

$$= \frac{volume\ of\ tank(m^2)}{flow\ per\ unit\ time\ (m^2/h)}$$

Factors such as eddy currents, short circuits, etc. also have an important effect when water flows through the container. The actual retention time can be determined by using coloured dyes or by some other method.

12.7.2 Percentage efficiency of retention/efficiency of displacement

This is determined by dividing actual retention time by nominal through flow time:

$$\%\ efficiency\ of\ retention = \frac{Actual\ retention\ time}{Theoretical\ retention\ time} \times\ 100$$

The percentage must be higher than 30.

12.7.3 Upward flow velocity

$$Upward\ flow\ rate = \frac{area\ (m^2)}{flow\ (m^3/h)}$$
$$=\ m^3/m^2/h\ or\ m/h$$

$Normal\ upflow\ velocity\ is\ 1\ m/h$

$Weir\ overflow\ rate\ should\ not\ be\ more\ than\ 10\ m^3/h/m\ weir\ length,$

$$= \frac{flow\ (m^3/h)}{weir\ length\ (m)}$$

12.8 Sludge draw-off

The ideal way to operate a sedimentation tank would be to remove sludge at the same rate as it is formed. It is important to know what quantity of sludge to be expected per day for the purpose of disposal.

Sludge draw- off is different for different types of tanks (see discussions on tanks). Scrapers move the settled solids to a sludge hopper from where it is removed. In other types a sludge removal arm is installed.

It revolves slowly around a centre shaft; a tapered tube with openings spaced along the length. Instead of a scraping action, the settled solids are picked up by a slight suction action and are conveyed through the arm to be discharged from the bottom of the tank centre.

12.9 Control and records

To determine efficiency of operation, collect a sample of effluent in a glass bottle and shake well. Take a turbidity reading. True turbidity may be determined by allowing the water to stand for 1 hour and then do a test on the supernatent.

If a sample clarified effluent is filtered through a Whatman no 1 filter, the turbidity should be less than 1,0 NTU. A higher reading indicates that flocculation is faulty and that a high turbidity will also be obtained after the sandfilters, and will clog the filters rapidly.

The actual quality of sedimentation tank effluent can be judged on the length of filter runs between backwashes. Runs of less than 48 hours are unsatisfactory. Backlash water should not exceed 2% of the water which is filtered.

Records should be kept of filter runs, amount of water through sedimentation tanks, amount of sludge removed and sludge withdrawal intervals.

Activity 12.1

1. Name 8 factors which influence sedimentation.
2. The total daily flow is 9 000 m3/d. The suspended solids after adding the flocculant is 50 mg/l and the suspended solids concentration is 450 mg/l for the settled sludge. Calculate the volume of sludge to be extracted per day.
3. Name 4 types of sedimentation tanks in use in South Africa.
4. The flowrate through a horizontal flow tank 20 m long, 7,5 m wide and 4 m deep, is 83,33 l/s. Calculate the retention time and upward flow velocity.
5. What are the normal values for:
   a) upflow rate
   b) weir overflow rate.

Self-Check

I am able to:	**Yes**	**No**
• Explain the principles of sedimentation		
o Factors affecting the process - size, temperature and viscosity of water, depth, surface area, inlet and outlet flow rate		
• Identify common problems		
o Short circuiting		
o eddy currents		
o convection currents		
o wind action		
o algae		
• Identify and describe types of tanks		
o Fill and draw		
o horizontal flow		
o vertical flow with sludge blankets		
o vertical flow without sludge blanket		
o radial flow tanks		
• Perform the following calculations:		
o Nominal or theoretical retention time		
o % efficiency of retention		
o upward flow velocity		
o weir overflow rate		
• Describe sludge draw-off		
• Demonstrate maintaining control and records		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 13

Filtration

Learning Outcomes
On completion of this module, students should be able to:

- Explain the purpose and principles of filtration
- Describe slow sand filters
  - Theory, description of units and design parameters, quality of raw water and optional pretreatment, filter media and cleaning, maintenance and records, advantages and disadvantages
- Describe rapid gravity sand filters
  - Theory, description of units and design parameters, filter media, filter and backwash rate, backwash procedure, maintenance and records
- Describe pressure sand filters,
  - advantages and disadvantages
  - operation
- Describe other types of filters
  - Upward flow filters (contact bed sand filters)
  - diatomaceous filters
  - multimedia filters
- Explain deposits on sand grains
- Describe operational problems
  - Mud balling, cracks, broken nozzles, air locks, algae and slime organisms
- Describe how to bring a new filter into operation
- Describe how to care for a sand filter

13.1 Introduction

In this module you will learn more about the complexities of the filtration process. On completion you should understand the principles and theory of filtration.

You should also know the difference between different sand filters concerning construction, medium, sand grain size, filtration rates, etc. This module also explains backwashing and cleaning procedures as well as maintenance and the operation of filters including operational problems encountered.

You should be able to draw the different types of filters. Sand filters are not merely "strainers" for removing suspended solids larger than the spaces or pores between the sand grains.

Since colloidal clay and colouring matter and bacteria are smaller than these pores, their removal involves complex processes. Filter design, therefore, involves a consideration of many factors favouring these processes. Filtration can be regarded as the result of a number of processes which occur within the filter medium:

- Adsorption
- Flocculation
- Sedimentation
- Biological action

The ideal filter media possesses the following characteristics:

- Coarse enough for large pore openings to retain large quantities of flocculant yet sufficiently fine to prevent passage of suspended solids;
- Adequate depth to allow relatively long "filter runs"
- Graded to permit effective cleaning during backwashing.

13.2 Slow sand filters

13.2.1 Theory, description of units and design parameters

Slow sand filters (see, **Figure 13.1**) should be so designed that water flows at a slow rate (2-5 m/d depending on properties of water to be filtered) through the sand.

So that coarser suspended solids are caught in or near the surface of the bed to form a fine porous layer having a large total surface area, whereby absorption of impurities in the layer and underlying sand is facilitated. This requires a large area and slow rates to ensure surface contact and adsorption.

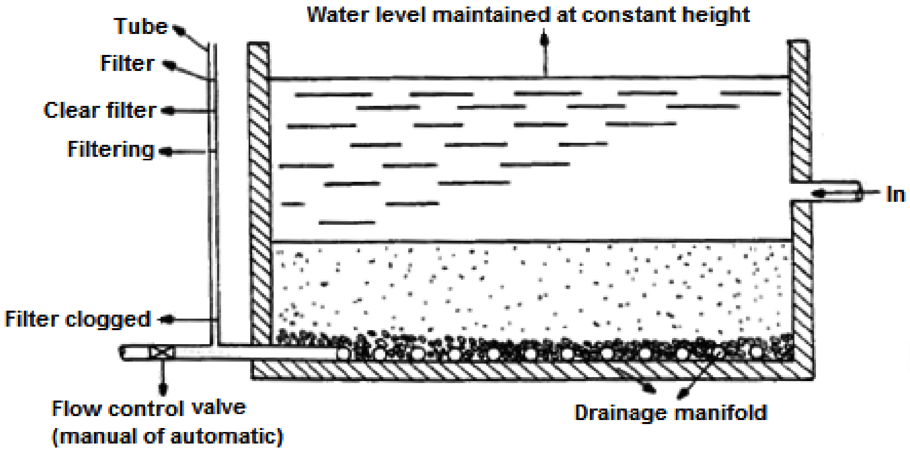


Figure 13.1 Slow sand filter

The slow sand filtration rate gives the bed a greater efficiency in removal of flocculant particles or suspended matter, than is obtained in a rapid gravity sand filter.

A slow sand filter should be operated for some days after cleaning before the filtrate can be used. (Allow time for slime growth which aids in filtration.) Filters are provided with a loss of head meter, an apparatus to control the flow and enough space for ± 1 m water above the sand.

13.2.2 Quality of raw water and optional pre-treatment

Provision for flocculation is unnecessary but can be initiated with a small amount of flocculant. Water should be relatively clear. Turbidities of up to ± 30 NTU can still be treated as the process is very slow and will remove all suspended and colloidal matter.

If the turbidity is much higher, it would be advisable to couple the process to a fill and draw sedimentation tank for pre-sedimentation. The clearer the raw water, the longer the filter runs. Colour removal is not obtained due to a lack of chemical treatment (flocculation).

Algae, which reduce filter runs, can be controlled by pretreatment with copper sulphate when a pre-sedimentation basin is available. Pre-chlorination will secure' longer filter runs as it destroys excessive slime organisms and algae.

13.2.3 Filter media and cleaning

The filter medium used is a fine sand of nearly uniform size (± 0,4 mm diameter) with no provision for backwashing. The sand bed may be 300 - 700 mm thick supported on a bed of gravel.

When the required quantity can no longer be filtered, the filter must be drained and allowed to dry out. The top 20 - 60 mm sand is removed, washed clean and replaced or replaced with clean sand before the filter can be used again.

A minimum of 3 filters is recommended. If one filter is put out of operation and cleaned, water can still be produced in the other. Raking of the sand surface will lengthen the time between scrapings.

- **Advantages of a slow sand filter:**
  - No need for coagulation facilities
  - Equipment is simple
  - Suitable sand readily available
  - Supervision is simple
  - Effluent is less corrosive and more uniform in quality than chemically treated water
  - Give effective bacterial removal

- **Disadvantages when compared with rapid gravity sand filters**
  - Large area required, with correspondingly large structure and volume of sand and higher structural costs.
  - Less flexible in operation.
  - Not economical with raw water turbidities more than 30 NTU for prolonged periods, unless pre-sedimention will secure such turbidities in settled water.
  - Less effective in removing colour
  - Poor results with water of high algal content unless pre-treatment is practiced.

In general, the advantages justify their use for small plants not under technical supervision, where relatively clear surface waters are to be treated.

13.2.4 Maintenance and records

The top sand layer should be kept in good condition by scraping and skimming of sand, to allow a satisfactory filtration rate.

Filter should be kept free of algae (clog easily due to lack of flocculation process and slow filtration). It can be removed by the addition of HTH.

Keep record of:

- Quality of water filtered
- Filtration rate (filter runs)
- Loss of head
- Amount of sand replaced and how regularly
- Turbidity of raw water

13.3 Rapid gravity sand filter

13.3.1 Theory, description of units and design parameters

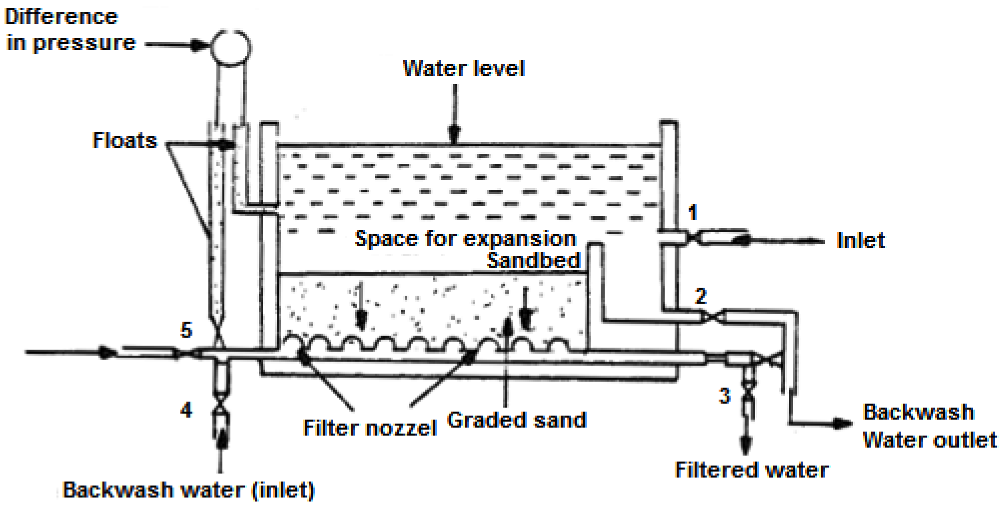


Figure 13.2 Rapid gravity sand filter

Rapid gravity sand filters (see, **Figure 13.2**) are usually coupled to a process which includes flocculation and sedimentation.

When water passes through the filter, suspended particles and flocculant material come in contact with the sand grains and adhere to them.

This reduces the size of the water passages and a straining action results. In time more and more material is trapped in the sand bed, the pores clog and the hydraulic loss through the bed becomes excessive.

The filter is then backwashed to remove the entrapped material. The structure of this filter is almost identical to a slow sand filter.

13.3.2 Filter media

As the efficiency of the filtration process depends to a large extend on the sand grain size, it is important that it should be as uniform as possible (± 0,6 mm) with a uniformity coefficient being no greater than 1,8.

Furthermore it should be chosen-not to disintegrate during the backwashing process. The depth of the sand bed must be about 450 - 750 mm supported by an under drain which consists of the following:

- Perforated pipe of cast iron or asbestos-cement.
- False bottoms of concrete or steel, with nozzles of plastic or metal evenly spaced at not more than 250 mm from each other and not less than 250 mm from the sides. (This is to prevent short circuits at the perimeter).
- A porous carborundum plate attached and supported by stainless steel or concrete.

A layer of gravel (1,5 - 7,0 mm) can be placed on top of the nozzles to a depth of 50 - 100 mm to serve as a carrier for the sand bed. The filter sand should preferably be supported by a 7,5 cm layer of coarse sand, having an effective size between 0,8 and 2,0 mm, placed over the gravel.

(The effective size of sand grains is defined as the point where 10% of the grains per mass are smaller than 90% of the larger grains).

13.3.3 Filter and backwash rate

The turbidity of water should not exceed 10 NTU (if more - apply pretreatment).

A special valve and level control gear is needed to control the flow of effluent from the filter so that the sand bed will always be covered with water when in operation. It is therefore important that both the inlet and outlet of the filter be controlled.

The flow rate can vary from 4 - 12 m/h depending on the sand grading and other factors. The backwash rate must be at least 25 m/h to ensure sufficient cleaning.

Worked Example 1

Calculate the volume of water filtered through a rapid gravity sand filter 5 m in length and 2 m wide at a maximum flow rate of 5 m/h.

$$\begin{aligned} Area\ of\ filter &= 5\,m \times 2\,m \\ &= 10\,m^2 \end{aligned}$$

$$\begin{aligned} Flow\ rate &= surface\ area \times filtration\ rate \\ &= 10\,m^2 \times 5\,m/h \\ &= 50\,m^3/h \end{aligned}$$

Worked Example 2

100 m^3 of water is filtered per hour in the above filter. Is this filter overloaded or not?

$$\begin{aligned} Filtration\ rate &= \frac{flow\ (m^3/h)}{surface\ area\ (m^3)} \\ &= \frac{100\ (m^3/h)}{10m^2} \\ &= 10\,m/h \end{aligned}$$

∴ filter is overloaded

Worked Example 3

Calculate the flow to backwash the above filter at a flow rate of 25 m/h.

$$\begin{aligned} Flow\ rate &= surface\ area\ x\ filtration\ rate \\ &= 10\,m^2 \times 25\,m/h \\ &= 250\,m^3/h \end{aligned}$$

13.3.4 Backwash procedure

(*For rapid gravity sand filters and pressure sand filters*). Filters should be backwashed when the loss of head reaches 2,4 - 3 m. At least two filters should be provided to ensure continuation of the process.

Rapid gravity and pressure sand filters are cleaned by backwashing the sand by reversing the flow upward through the bed to remove mud, floc and other impurities lodged in the sand with the aid of air (from an air blower) passing through the sand, the process of cleaning becomes more efficient by a rubbing or scrubbing action to loosen the particles and preventing mudballs.

The quantity of air required is about 400 l/min/m^2. Once the bed has been treated with air, water is passed through the filter in a reverse direction. The upward flow rate required is at least 25 m/h to ensure that the sand bed is fluidised.

There should be sufficient free-board available so that the bed can expand during this process without sand being lost. The minimum quantity of water needed is 500 l/min/m^2. The filter should not be washed absolutely clean (± 75 NTU can be used as an arbitrary figure).

Refer to **Figure 13.2** for the backwashing procedure.

The procedure is as follows:

1. Close the inlet valve (no. 1) and allow the water to drain through the filter to just above the sand level.
2. Close the filtrate valve (no. 3) and open the backwash outlet valve (no 2).
3. Start the air blower and open valve no 5 slowly until fully open. Pass the air through the bed at least 5 min. Notice whether the air distribution is spread over the whole area of the bed, if not report to person in charge.
4. Close valve no 5 slowly and stop air blower.
5. Start the backwash pump and open valve no 4 slowly until the required flow is reached (check flow meter).
6. Backwash the filter until fairly clean. Use a stick to check for fluidity at all parts (the sand bed should not be felt).
7. Close valve no 4 slowly, stop backwash pump.
8. Close valve no 2 and open valve no 1. If the filter is not of the automatic type, allow it to stabilise for about 30 min and then bring it slowly into operation. Valve no 3 must be opened as soon as the filter is ready for use.

13.3.5 Maintenance and records

Records must be kept of:

a) Differential pressure and filter runs.
b) Volume of wash water used and time backwashed.
c) It is important to see whether the air and water is evenly distributed over the sand bed. If not, it will lead to deterioration of filtered water.
d) Check for mudballing.
e) Measure the filter bed at least twice per year and record the depth. Fill up if-needed.
f) Brush the filter walls daily to keep it free from growths. Apply pre-chlorination for this purpose.
g) Measure and record turbidity of filtered water regularly.

h) Regularly fill recording instruments with ink and change flow charts.

13.4 Pressures sand filters

13.4.1 Description, advantages and disadvantages

The operation is very similar to that of a rapid gravity sand filter. The graded sand bed is placed in an enclosed cylinder, in a horizontal or vertical position, see **Figure 13.3**.

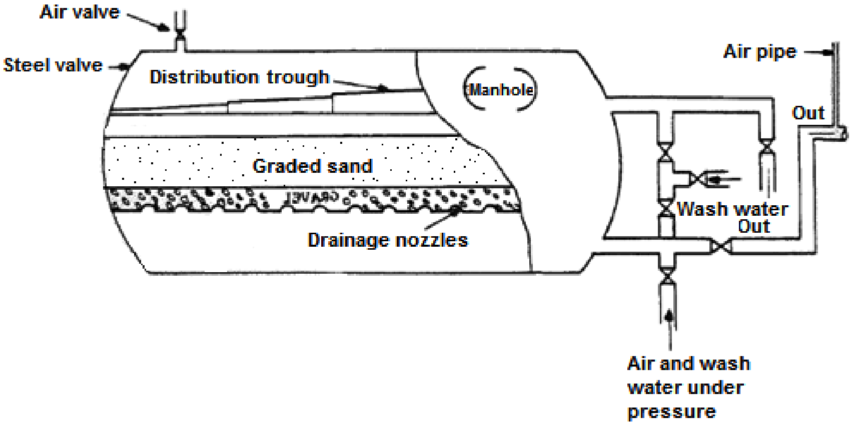


Figure 13.3 Pressure sand filter

- **Disadvantages**
  - Because the water is fed under pressure, it is difficult to dose any chemicals which may be needed.
  - Pressure filters are completely closed and the water and sand is therefore not visible. The efficiency of the backwashing process can thus not be observed.
  - The shape of the filter makes an effective wash water distribution manifold design impossible.
  - Inspection of sand, nozzles, draw-off system etc. as well as any repairs needed are difficult.
  - Because these units operate under pressure, there is always the temptation to pass excessive amounts through.

- **Advantages**
  - Popular in small water plants that process groundwater for softening and iron removal.
  - Are assembled completely in the factory and transported for convenient installation.

13.4.2 Operation

- Pumps are normally used to pump water through a pressure sand filter. The following are important in the operation of the filter:
- The water level in the pump sump must not drop too low otherwise air will be sucked into the pump and this will cause damage to the pump.

- Due to the fact that the sand bed is not visible, the temptation may be high to overload the filter. For this reason, it should be fitted with a pressure meter so that the filter can be backwashed at a given pressure.
- Each filter should be fitted with an air valve, automatic or manually operated. Air should be expelled and the filter always kept full of water. If an automatic air valve is supplied, the valve should be checked regularly and maintained in a good working condition. Air valve spares should be kept in stock.
- The condition of the sand bed should be inspected through the manhole cover at least twice a year.
- Similar records, as in the case of rapid gravity sand filters, should be kept.

13.5 Other types of filters

13.5.1 Upward flow filters (Contact bed filters)

Contact bed sand filters are used to treat water with a constant low turbidity. A flocculant is mixed with the raw water and passed from the bottom to the top through a contact sand bed filter.

At the bottom, coarse gravel is placed followed by finer gravel, the coarse sand and fine sand on the top layer.

The water, mixed with the flocculant, enters the bed at the bottom; flocculation takes place around the course gravel particles with filtration through the bed. Backwashing is done in the normal way by increasing the velocity to at least 25 m/h.

13.5.2 Diatomic filters

Diatomaceous earth filters generally have been limited to swimming pools, industrial applications, portable field units and installations for small towns.

The filter medium is supported on a fine metal screen, porous ceramic material or synthetic fibre. The filtration cycle consists of pre-coating the medium, filtering water to a predetermined head loss, and removing the filter cake.

During the precoat operation, slurry of diatomite in water is used to deposit a filter on the screen. Raw water with a small amount of diatomaceous earth (body feed) is drawn through the filter formed by the initial layer.

Body feed continually builds the filter so that surface clogging is minimised. When maximum pressure drop or minimum filtration rate is reached, the filter medium is washed by reversing the flow discharging the dirty cake to waste.

The cycle is then repeated. Common filtration rates is 1 - 3,5 $l/m^2/s$. This type of filter is especially adapted to the clarification of waters of low turbidity, when suspended solids and algae may be removed without coagulation.

13.5.3 Multimedia filters

A layer of anthracite about 300 mm deep, with a diameter of 1 ,2 - 2,4 mm is placed on top of the sand. Between the two layers is a layer of bidum (gauze) to prevent sand from going through.

The depth of the sand is ± 500 mm. These conditions create an ideal filter with the coarsest material at the top, gradually becoming finer towards the bottom. This means that the larger floc would be removed in the upper regions of the bed and the finer floc in the deeper regions.

The advantage of a dual media filter is that the flow rate through the filter can be at least twice that through a normal filter. Flow rates of at least 12 m/h can easily be maintained with turbidities less than 1,0 NTU.

13.5.4 Deposits on sand grains (expansion of sandbed)

It can sometimes happen that the volume of the sand bed increases and the bed therefore expand. This is the result of $CaCO_3$ and manganese dioxide precipitating around the sand grains, which act as a nucleus and continue to grow in this way.

It is also the result of poor control over the lime dose and pH. The problem can be rectified by placing slightly corrosive water on the filters for a few months so that the $CaCO_3$, is gradually reduced.

When the pH of the water no longer increases after passing through the filter, it can be assumed that very little $CaCO_3$ remains.

13.6 Operational problems

13.6.1 Mud balling

The presence of mud balls in the sand indicates incomplete washing. This may be due to insufficient rate of flow of wash water or to the use of too short a washing period.

Mud balls are pieces of clay within the sand bed, which begin in much the same way as snowballs. Sand particles adhere to each other due to clay or floc and grow in size to that of a soccer ball or even larger.

It tends to accumulate where there is unevenness in the upward flow of the wash water. Mud balls have the tendency to clump together during the backwashing process.

While back- washing, these mud balls, with a higher density than sand, will sink deeper into the sand bed and will result in clogged areas in the bed.

Unchecked formation of mud balls will eventually result in large balls sinking through the agitated sand during the washing process and then collecting between the gravel and the sand. It's presence can only be detected by turning the sand over with a fork.

The easiest way to break up mud balls is to let the blower run for at least 30 minutes and then to wash with water. Repeat the process until all the mud balls have been broken up.

13.6.2 Cracks

Mud balls can also be identified by cracks forming in the sand bed or along the side walls. Cracks also form along the sidewalls when loss of head has reached its maximum (**Figure 13.4**).

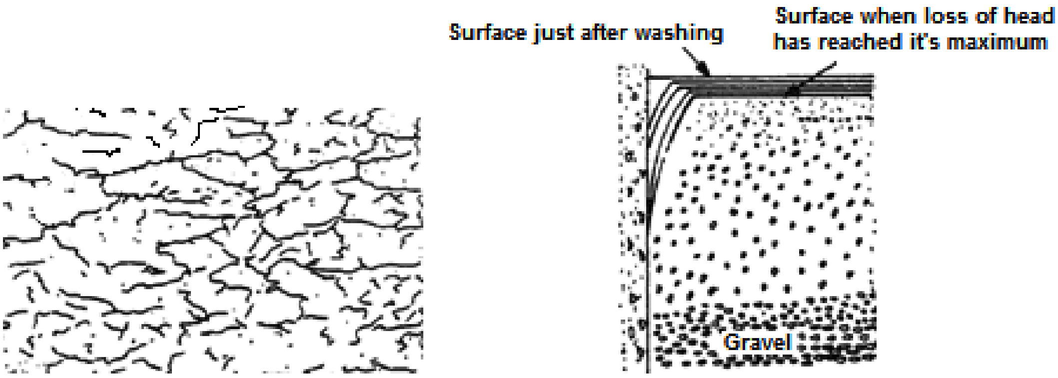


Figure 13.4 Cracks

The presence of mounds and craters in sand beds indicates that the under drains or strainers are broken thus permitting rapid rates of filtration and washing over a restricted area and penetration of sand into the gravel or upheaval of gravel into the sand.

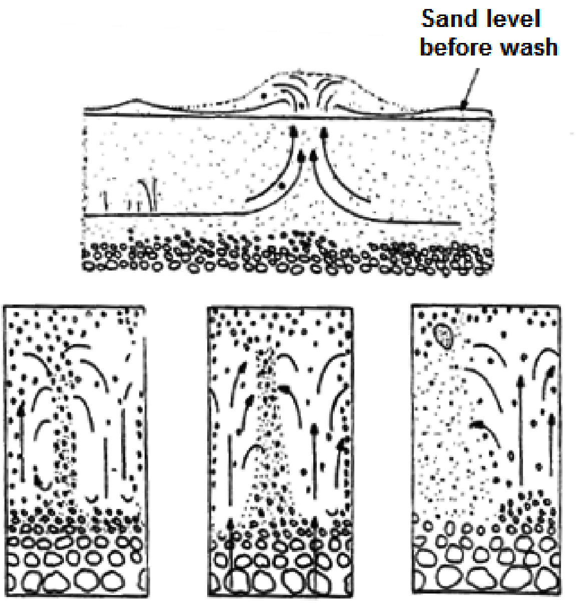
Clogged airlines, under drains or strainers lead to dead areas in the filters, the presence of is indicated by a quiescent area when the bed is backwashed.

Broken or clogged under drain systems should be repaired at once, otherwise the bed will not function correctly and eventually more costly repairs will be required.

13.6.3 Broken nozzles

If a filter nozzle is broken or blocked, sand boiling may occur with a resulting deterioration of the filtered water. It is not necessary to remove all the sand when replacing a broken nozzle, but this particular area in the filter may be boxed off.

Drain the bed and place a large pipe or casing above this point. Remove the sand in the pipe while pushing it downward until the nozzle is reached. The nozzle can then be replaced with the minimum effort.



(a)
Newly
constructed
bed

(b)
After several
washes

(c)
Mudballs
forming
dogged area

Figure 13.5

13.6.4 Air locks (air binding)

Air binding is caused by excessive negative pressures in the sand bed. These permit gases released from the water to lodge in the bed and under drainage (if the head loss becomes high) system and reduces the capacity of the filter.

When the head loss becomes high, difficulty with air binding may occur. Another adverse effect of air binding is the excessive foaming which results on the filter surface when backwashed. The foam contains a lot of sand which is then lost.

Some of the air can be eliminated by closing the outlet valve for a few minutes. Air bubbles will then escape and the filter can be placed in operation again after a few minutes.

Other precautions are the prevention of negative pressure, the control of algae growth, ensuring that the water does not become supersaturated with air, and if possible, the prevention of a rise in the waters' temperature as it flows through the plant.

13.6.5 Algae control and slime organisms

Micro-organisms in the sand may bind together organic material, clay and gelatinous floc (especially if poly-electrolytes are used) to cause the bed to compact and shrink. The bed can be treated as follows:

- **Chlorine**

Lower the water level to about 300 mm above the top of the sand. Scatter about 500 g HTH (70% CaOHCl) for each 10 m^2 of filter area on the water. (If NaOHCl is used, use about 3l for the same area).

Start the air blower and mix the chlorine throughout the bed. Let the band stand for 24 hours and wash thoroughly before returning to operation.

- **Caustic soda**

Wash the bed thoroughly, leaving about 300 mm water over the sand. Dissolve 5 - 10 kg caustic soda for each m^2 of filter area. Allow to stand for 6 - 12 hours. Wash bed thoroughly. Caustic soda will dissolve alum floc and organic matter coating the sand grains.

- **Sodium chloride**

Ordinary table salt can also be used to destroy slime organisms. Reduce the water to ± 300 mm; scatter about 7 kg salt for each m^2 area. Start the air blower and bubble air through the bed for 10 minutes.

The salt will dissolve and disperse evenly throughout the bed. Let the bed stand for 24 hours and wash thoroughly before returning to operation. Pre-chlorination may be applied to control algal growth on filter walls.

13.7 Bringing a new filter into operation

- Backwash the filter. Before turning off the backwash water, slowly close the valve over a period of 5 minutes to ensure that the sand is properly graded.
- Drain the -filter completely.
- Examine the sand on the filter and remove fine sand completely.
- Repeat the process every time the filter is washed until all the fine sand is removed.
- The same procedure should be followed whenever more sand is added to the filter.

13.8 Care of sand filters

As the filters are justly called the heart of the purification works, their care is very important. Attention must be paid to the following:

- The depth of the sand bed should be measured and recorded at least twice a year.
- The filter head loss should not exceed 2,5 m (25 kPa). A negative pressure is then possible and floc may be drawn through.
- The filters should be thoroughly backwashed.
- Blocked or broken nozzles should be watched for as well as the uneven distribution of air over the bed.
- The bed should be inspected at least twice a year for mud balls.

- All filter control gear such as pressure gauges, flow metres and valves should be regularly checked for proper operation.

Activity 13.1

1. Name the procedures to be followed when a new rapid gravity sand filter is brought into operation.
2. Name the causes of expansion of the sand bed.
3. Describe the procedures to replace a broken nozzle without removing the whole sand bed.
4. Discuss the advantages and disadvantages of pressure filters when it is compared to rapid gravity sand filters.
5. Which precautionary measures should be taken in the caring of sand filters.
6. Name four advantages of slow sand filters.

Self-Check

I am able to:	**Yes**	**No**
• Explain the purpose and principles of filtration		
• Describe slow sand filters		
o Theory, description of units and design parameters, quality of raw water and optional pretreatment, filter media and cleaning, maintenance and records, advantages and disadvantages		
• Describe rapid gravity sand filters		
o Theory, description of units and design parameters, filter media, filter and backwash rate, backwash procedure, maintenance and records		
• Describe pressure sand filters		
o advantages and disadvantages		
o operation		
• Describe other types of filters		
o Upward flow filters (contact bed sand filters)		
o diatomaceous filters		
o multimedia filters		
• Explain deposits on sand grains		
• Describe operational problems		
o Mud balling, cracks, broken nozzles, air locks, algae and slime organisms		
• Describe how to bring a new filter into operation		
• Describe how to care for a sand filter		

If you have answered ‘no’ to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

Module 14

Disinfection

Learning Outcomes

On completion of this module, students should be able to:

- Describe the purpose, principles and methods of:
    - chlorine, hypochlorite, chlorine dioxide, chloramines ozone, uv irradiation, heat
    - prechlorination, post chlorination, superchlorination
- Describe the theory of chlorination and factors affecting it
- Describe the formation of chlorinated compounds producing tastes and odours
- Describe breakpoint chlorination
    - monochloramine, di- and trichloramine and other substances
- Explain the use of chloramines in distribution systems
- Describe the properties of:
    - chlorine gas
    - hypochlorites
- Explain the storage, handling and changing of chlorine cylinders
- Describe the following with regard to gas chlorinators
    - cabinet
    - wall
    - cylinder mounted
- Explain the operation of gas chlorinators
    - basic components
    - maintenance
    - starting and stopping procedures
- Describe hypochlorite solution feeders
    - pumps and constant head feeders
    - operation difficulties
- Describe residual chlorine measurement
    - DPD and orthotholidene methods only
- Explain how to control effective chlorination in terms of:
    - dosage
    - continuous feed
    - chlorine
    - bacteriological tests
- Explain how to detect chlorine gas leaks
- Describe safety measures and first aid
- Maintain records

14.1 Introduction

This module deals with chlorination, the effectiveness thereof and measurement of effectiveness. You will learn about the theory and principles of methods and operation.

You will also learn about residual chlorine measurement and the methods used to control effective disinfection. Elementary first aid and safety measures will be discussed and the records that need to be kept.

As chlorination is a very important part of the purification process, it is advised that you know the abovementioned aspects well.

14.2 Purpose and principles

Although a large percentage of bacteria are removed by sedimentation and carried off with the sludge, the remainder are mostly retained on/in the sand filters. Those in the sand filters multiply and flow out with the effluent.

Sometimes there are even more bacteria in the effluent than in the influent and may endanger human health. Disinfection in water is accomplished by killing bacteria and other organisms it may contain.

This process kills coliform bacteria while reducing the number of others greatly. Complete sterilisation (killing of all living organisms) will be attained by boiling water.

14.3 Methods

14.3.1 Pre-chlorination

Pre-chlorination can be applied under the following conditions:

- to oxidise substances such as hydrogen sulphide, iron, manganese and ammonia which occur in raw water
- to control algae and slime organisms in the plant
- improves coagulation, reduces the load on the filters.

14.3.2 Post chlorination

Involves chlorination of final purified water to ensure that it is disinfected and free of harmful bacteria. It can be done at the treatment plant or at points along the distribution line such as reservoirs.

14.3.3 Super-chlorination:

Application of chlorine to leave a large residual is often used to remove tastes and odours. It must be followed by de-chlorination by passing water through activated carbon filters.

In water treatment, various chemicals/methods are employed to destruct harmful bacteria.

- **Chlorine**

The most generally used substance and will be discussed at a later stage.

- **Hypochlorite**

Calcium hypochlorite and sodium hypochlorite are commonly available and mainly used at small plants.

- **Chlorine dioxide**

Has found acceptance in potable water treatment, because it does not form trihalomethanes. It is however more expensive than chlorine, is soluble in water over a wide pH range.

As a liquid it is unstable and unsuitable for storage in cylinders and consequently it is always generated as a gas on-site and immediately dissolved. It has a theoretically very high oxidising capacity and a proven high toxicity to microorganisms.

- **Chloramines**

Chlorine can be used in combination with ammonia for disinfection of water. Monochloramine requires a longer retention time, compared to chlorine, for effective killing of bacteria.

- **Ozone**

0^3 is an active oxidising agent and is obtained when clean dry air is passed between two highly charged electrodes and is passed between two highly charged electrodes and is only stable for about 4 minutes.

Ozone is very expensive to generate and trained personnel are required to operate the generators.

- **UV irradiation**

Ultra violet rays generated by the sun also destroys bacteria and can be artificially generated by suitable lamps to give a more intense and controlled radiation.

The best results are obtained when water is very clear and the depth of flow is less than 200 mm. About 40 kV hours of electrical energy is needed to disinfect 1 m^3 of water.

- **Heat**

Boiling will sterilise water, i.e. kill all organisms whether pathogenic or not. It is however not practicable to use this method at a waterworks.

14.4 Theory of chlorination and factors affecting it

Chlorine rapidly hydrolyses when added to pure water to form hydrochloric acid and hypochlorous acid:

$$Cl2 + H_2O \approx HCl + HOCl$$

The hypochlorous acid then partly dissociates to form hydrogen hypochlorite ions:

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

The three forms of free available chlorine involved (molecular chlorine ($C1_2$), un-ionised hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) exists together in equilibrium. Their relative proportions are determined by the pH value and temperature.

In water chlorination, pH is the most important factor governing the relative proportions as shown in **Figure 14.1**. If the pH drops below 2, the predominant form is Cl_2; between pH 2 and pH 7 the equilibrium is in favour of HOCl.

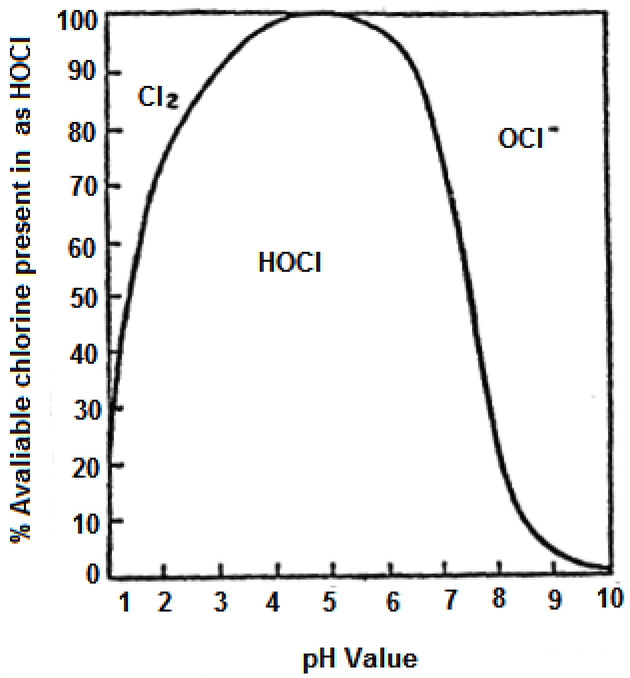


Figure 14.1 Effect of pH value on the form of chlorine

At pH 7,4, HOCl and OCl^- are about equal, while above this, increasing proportions of OCl^- is present. Above 9,5, all the available chlorine is present as OCl^-.

The chlorination properties of Cl_2 is much better than for the other two forms, but is not carried out at this low pH.

OCl^- is a slower reacting form of disinfectant than HOCl and it is therefore important to bear in mind that allowance should be made for longer contact times at higher pH values, to ensure efficient disinfection.

Rate of disinfection also depends upon other factors such as concentration and form of available chlorine residual, contact time, temperature and other factors.

14.5 Formation of chlorinated compounds producing tastes and odours

Large concentrations chlorine residual may cause undesirable taste. When a water supply contains phenols, the addition of chlorine to water will result in disagreeable tastes due to the formation of chlorophenol compounds. These tastes may be eliminated by adding ammonia to water just before chlorination.

14.6 Breakpoint chlorination

The presence of impurities in water has an influence on the chlorination process. Ammonia, generally associated with polluting matter, has a profound influence upon the process.

The following reactions will take place when chlorine is added to water containing ammonia:

$$NH_3 \xrightarrow{Cl_2} NH_2Cl \xrightarrow{Cl_2} NHCl_2 \xrightarrow{Cl_2} NCl_3$$

ammonia monochloramine dichloramine trichloramine

14.6.1 Monochloramine

Addition of chlorine in a ratio of less than 5:1 ammonia will result in the formation of monochloramine. It is also a disinfectant but needs a longer contact time to kill bacteria than chlorine.

14.6.2 Dichloramine and trichloramine

Dichloramine will form with a ratio 5:1, while trichloramine will form in a ratio up to 10:1. In concentrations less than 0,1 mg/l, trichloramine can be detected by smell.

At ratios more than 10:1, only trichloramine will be formed. This compound is very unstable and dissociates easily to form nitrogen gas and hydrochloric acid. This point is called breakpoint chlorination.

Before this point the total residual chlorine will increase with increasing dosages of chlorine, until at breakpoint, the chlorine content will decrease sharply· After breakpoint the free available chlorine concentration will increase corresponding to the added amount.

14.6.3 Other substances

Chlorine in water may also react with inorganic substances (such as iron, manganese and sulphur) and organic matter present in water. These substances also have a demand for chlorine to be satisfied and thereby complicate the disinfection process.

The chlorine demand of waters will vary and proper control of disinfect ion is ensure that enough chlorine is added in excess for purposes and to have enough contact time available to kill bacteria. (at least necessary to disinfection 30 minutes). A typical breakpoint chlorination curve is shown in **Figure 14.2**.

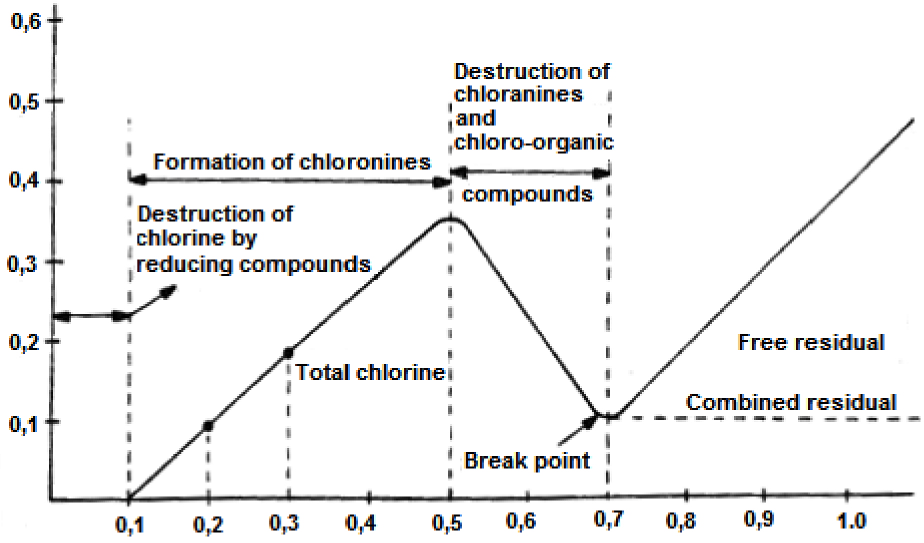


Figure 14.2 Typical breakpoint curve

Four definite regions can be seen:

1. The region where chlorine is broken down by reducing substances.
2. Region where chloro-organic compounds and chloramines are formed.
3. Region where chloramines and chlorine- organic compounds are broken down.
4. Region beyond the breakpoint where free residual chlorine and a limited amount of organic chlorine compounds, which are not destroyed by excess chlorine, are found. In this region the chlorine concentration will increase in uniform proportion to the excess chlorine added. The purpose is to have free residual chlorine present in the water. At this point the more volatile organic-chlorinous smells as well as other unpleasant smells will no longer be noticed.

14.7 Use of chlorines in distribution systems

Monochloramine as a disinfectant needs a longer contact time, compared to chlorine, but is more stable and may be effective for days. The addition of ammonia, after applying breakpoint chlorination, is commonly used to stabilise chlorine when water is to be pumped over long distances or where the retention time in reservoirs is a couple of days.

This may be done by adding ammonia gas at a ratio of 1:5 chlorine, e.g. if 1,0 mg/l of free available chlorine is determined after breakpoint, 0,2 mg/l ammonia gas is then added and mixed with the water. Ammonium sulphate may also be used in a ratio of 1:1.

14.8 Properties of chlorine gas and hypochlorites

14.8.1 Chlorine gas

- Chlorine is very dangerous. A suitable gas mask must be available when handling chlorine gas.
- Chlorine gas is yellow-green in colour, about 2,5 times denser than air, an atomic mass of 71,0 amu. Thus in a case of a chlorine leak, chlorine gas will always be found in the lower areas of a room. Provision for ventilation should be at both ceiling and floor level, unless an extraction fan is provided.
- Chlorine gas, in the dry form, is not corrosive to most metals. When mixed with water, it is very corrosive and therefore plastic material is used to transport the mixture.
- About 1 kg/h may be extracted from a 68 kg cylinder and about 7 to 10 kg of chlorine may be extracted from a ton cylinder before problems of freezing will occur.
- 1 kg of chlorine liquid will produce 456 litres of gas at normal temperature and pressure.
- Chlorine is a strong oxidising agent; it destroys bacteria and reacts with organic substances, iron, manganese, etc.

14.8.2 Hypochlorites

Hypochlorites are salts of hypochlorous acid and are also used as disinfectant at small plants.

14.8.3 Sodium hypochlorite

Available as a 15% available chlorine compound in liquid form it is more expensive than calcium hypochlorite, but, easier to dose with a constant head feeder.

It is however less stable and sodium hydroxide is added to the solution to stabilise it. Usually used in swimming pools, small waterworks and emergencies.

14.8.4 Calcium hypochlorite

Available as 25% available chlorine compound (chloride of lime) or as a 75% available chlorine compound (HTH). It is available in powder or granular form or pressed into a pill.

It is however not normally used for disinfection of sanitary systems. Special types of equipment are available for continuous dosing.

14.9 Storage, handling and changing of chlorine cylinders

14.9.1 Storage

- Chlorine cylinders are filled with liquid chlorine and thus under pressure. It must be kept in a cool place, out of direct sunlight.
- Empty cylinders should be marked and stored separately.
- 68 kg cylinders must be stored in an upright position, while 1 000 kg cylinders must be horizontal.
- Full cylinders must be brought into the dosing room 24 hours before using for equalisation with room temperature.
- Due to danger of leaks, store away from electrical equipment and switchgear in a separate well ventilated building.

14.9.2 Handling

- Cylinders should be handled with care to prevent damage and due to the fact that the gas is very dangerous.
- Always use a crane to lift cylinders upstairs.
- Fasten empty and full cylinders when transported.
- Keep a gasmask and spare cylinder of compressed air available for emergency situations.
- Obtain a wall chart from the suppliers on safe handling of cylinders.

14.9.3 Changing cylinders

- **68 kg cylinders**

Small cylinders are fitted with a protective hood which must remain screwed on when the cylinder is moved. Roll the cylinder upright by tilting it to one side.

When changing a cylinder, make use of the correct spanners. The cylinder should always be placed on a scale. Two persons should attend to changing of cylinders.

- The cylinder should be regarded as empty when 67 kg has been withdrawn.
- Close the valve with the correct spanner.
- Disconnect the feed pipe from the cylinder.
- Screw on the protective hood.
- Remove cylinder from scale and replace with a full cylinder.
- Remove protective hood, remove cap from coupling joint and clean thread with a steel brush.
- Replace old gasket, screw coupling nut on (not overtight).
- Open valve on cylinder and check for leakages.
- Weigh and record the mass Of the cylinder at least once per shift.

- **One ton cylinders**
  - Cylinders are supplied with two valves, also protected with a removable steel hood.
  - Clean and inspect thread of valves before connecting to the chlorinator.
  - Cylinders are placed horizontal with the valves in a vertical line (900 with the floor), one above the other.
  - Cylinders should be placed or suspended form a scale and weighed regularly, leaving about 5 to 10 kg of chlorine in the cylinder when changing.
  - Always use lifting gear to move cylinders, never roll them.

14.10 Gas chlorinators

The same instructions must be followed for cylinder mounted gas chlorinators, as described previously, regarding not emptying the cylinder completely, inspection and cleaning of threads, upright placing of cylinder and securing by chaining, marking empty cylinders, etc.

14.11 Operation of gas chlorinators

14.11.1 Basic components

Figure 14.3 Gas chlorinator

Basically all gas chlorinators (see, **Figure 14.3**) consist of the following:

- Gas inlet pipe connected to a vacuum regulator
- Vacuum regulator is equipped with a pressure relief valve, from which a safety vent pipe leads to the outside of the building, protected with an insect screen.

- The vacuum regulator is also connected to a calibrated rotameter which indicates the amount of gas (mg/s or g/h) passing through it.
- A rate control valve before or after the rotameter.
- A plastic venturi connected to plastic piping to transport the mixture of chlorine and water to the dosing point.
- Water passing through the venturi creates a vacuum to suck chlorine gas in from the vacuum regulator, via the rotameter and plastic piping to the venturi.
- A non- return valve at the venturi to prevent water entering the chlorinator.

14.11.2 Maintenance

The chlorinator itself may only be serviced or repaired by a trained artisan. The following may be done by the operator at least once per month:

- Close the valve on top of cylinder.
- Wait until rotameter registers zero flow.
- Close valve on water line.
- Remove glass rotameter, wash with methylated spirits, allow to dry and replace carefully.
- Remove nut at bottom of screen in water line and clean. Replace screen and fasten nut.
- Unscrew housing to non-return valve, clean and replace.
- Open water first, then chlorine supply and check for chlorine leakages.

14.11.3 Starting and stopping procedures

- **Starting**
- o Open water inlet to venturi and check the pressure meter.
- o Make sure the rate control valve is closed.
- o Open cylinder valve by one turn to allow max1·mum flow through valve.
- o Check pressure gauge on gas inlet line. (Not more than500 kPa depending on temperature).
- o Open rate control valve to required reading on rotameter.
- o Note mass of cylinder.

- **Stopping**
- o Close cylinder valve.
- o Operate until gas flow meter falls to zero. The pressure meter on the gas inlet line should also read zero.
- o Shut water supply to ejector.
- o Plug all disconnected lines with plugs provided.

14.12 Hypochlorite solution feeders

Positive displacement diaphragm pumps, mechanically or hydraulically actuated are used for metering hypochlorite solutions.

The hypochlorinator consists of water-powered pump placed by a positive displacement water meter. The meter register shaft rotates in proportion to the main line flow and controls a cam-operated pilot valve.

This in turn regulates the flow of water behind the power diaphragm to produce a discharge of hypochlorite proportional to the main flow. Admitting main pressure behind the pumping diaphragm balances the water pressure in the pumping head.

The advantage of this is that only a small force is needed for the discharge stroke, placing minimum stress on the diaphragm.

Another advantage is that the pump does not require electrical power. Hypochlorite dosages can be manually adjusted by changing the stroke length setting of the pump.

14.13 Residual chlorine measurement

Chlorination should be controlled by weighing cylinders and determining the available chlorine after a contact period of at least 30 minutes, preferably 1 hour. For control purposes, the DPD method is recommended.

14.13.1 DPD method

Compressed DPD tablets, are added to a water sample and the colour obtained is compared against a disc in a Lovibond comparator. The reading is given direct in mg/l.

There are 4 different tablets:

- DPD tablet no 1 is used for free residual chlorine.
- DPD tablets no 2 and 3 are used for mono- and dichloramine respectively.
- DPD tablet no 1 and 3 combined (or tablet no 4) are used for total residual chlorine.

In water purification, increasing amounts of chlorine must be added until a reading is found with DPD tablet no 1 after at least 30 minutes contact time with water. This will indicate that the breakpoint has been passed.

14.13.2 Orthotolidine method

A yellow brown colour is developed when chlorine reacts with orthotolidine, and is also calorimetrically measured. This method has the disadvantage that the various forms of chlorine cannot be distinguished.

14.14 Controlling effective chlorination

Enough chlorine must be added and mixed with the water to ensure an excess of free available chlorine after a contact period of at least 30 minutes.

Chlorine must be dosed continuously at a constant rate and mixed evenly throughout the whole volume of water. Chlorine dosage must be controlled by determining the mass of gas and regularly measuring the residual chlorine in the water.

This should be followed by bacteriological tests on a regular basis on samples taken from different points on the distribution system.

14.15 Detection of chlorine gas leaks

Concentrated ammonia is placed in a glass bottle. Use a piece of wire, fasten some cotton or waste at the end, and wet the cotton by dipping into the ammonia solution.

By moving the cotton near to connections, a leak of chlorine gas will be noticed by a white cloud of ammonium chloride which will form. If a leak is found, it should be fixed immediately.

14.16 Safety measures

- Always switch on extractor fan before entering the chlorine room.
- Make sure that gas masks are in good working order with sufficient compressed air in the container, with a spare container available.
- Always use ammonia to trace leaks, never soap and water.
- Two people should always be present when changing cylinders.
- Always use a crane to lift cylinders.
- Always use a new washer when cylinder is changed.
- Replace all metal pipes at least once a year.
- When copper tubing or electrical switchgear shows a green tarnish, gas is leaking and should be traced.
- Use rubber gloves and goggles when scattering dry chlorine powder on water.

14.17 First Aid

The following is only an emergency measure and victims should be rushed to hospital immediately. In case of chlorine poisoning the operator should:

- Remove victim from contaminated area.
- Call a doctor immediately.
- Start oral resuscitation immediately if breathing has stopped.
- Wash eyes repeatedly with water or 1% boric acid solution, if contaminated. Castor oil or olive oil may also be used. Prompt action is absolutely essential to protect eyesight.
- Keep victim warm and quiet.
- Place patient on his back with his head well back to maintain a clear air passage to the lungs.
- Give milk to relieve mild throat irritations.

- Get patient to hospital as soon as possible.

14.18 Records

Should be kept and filed of:

- Chlorine added to water.
- Chlorine residual remaining after 1 hour.
- Analysis (chemical and bacteriological) done on water samples.

Activity 14.1

1. At 7:00 on Tuesday, a chlorine cylinder weighed 200 kg and the next day at exactly the same time it weighed 181 kg. During the period, water had been pumped constantly at 400 m^3/hour. Calculate the average chlorine dosage in mg/l.
2. Name the steps that you should take to start a chlorine installation at a waterworks.
3. Give three products formed when chlorine reacts with ammonia.
4. Name an advantage and a disadvantage of using ozone as a disinfectant.
5. Name five factors which should be taken into account to ensure efficient disinfection when chlorine is used.
6. Under which circumstances would you use:
   a) prechlorination
   b) post chlorination

Self-Check

I am able to:	**Yes**	**No**
• Describe the purpose, principles and methods of:		
o chlorine, hypochlorite, chlorine dioxide, chloramines ozone, uv irradiation, heat		
o prechlorination, post chlorination, superchlorination		
• Describe the theory of chlorination and factors affecting it		
• Describe the formation of chlorinated compounds producing tastes and odours		
• Describe breakpoint chlorination		
o monochloramine, di- and trichloramine and other substances		
• Explain the use of chloramines in distribution systems		
• Describe the properties of:		
o chlorine gas		
o hypochlorites		
• Explain the storage, handling and changing of chlorine cylinders		
• Describe the following with regard to gas chlorinators		
o cabinet		
o wall		
o cylinder mounted		
• Explain the operation of gas chlorinators		
o basic components		
o maintenance		
o starting and stopping procedures		
• Describe hypochlorite solution feeders		
o pumps and constant head feeders		
o operation difficulties		
• Describe residual chlorine measurement		
o DPD and orthotholidene methods only		
• Explain how to control effective chlorination in terms of:		
o dosage		
o continuous feed		
o chlorine		
o bacteriological tests		
• Explain how to detect chlorine gas leaks		
• Describe safety measures and first aid		
• Maintain records		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 15

Distribution Systems and Stabilisation

Learning Outcomes

On completion of this module, students should be able to:

•

15.1 Introduction

The purpose of this module is to explain the basic causes of corrosion and to point out methods applied to protect pipelines against it.

It also includes stabilisation of water, the necessary tests to determine the stability indexes and the calculations thereof.

15.2 Corrosion and anti-corrosion measures

Corrosion is defined as the return of a material to its natural state. Corrosion may also be described as the deterioration of metal as a result of chemical or electro chemical attack (also called rust, oxidation).

In the corrosion process, energy is liberated when metal combine with other elements such as oxygen, chlorine, sulphur, etc. The corrosion rate depends on the environment. Raindrops absorb O_2 and other impurities e.g. CO_2, which combine with water to form harmful carbonic acid.

Gases and sea water can also be very harmful to distribution systems. Composition of soil plays a very important role in corrosion attack, especially in industrial areas. Pipes will not corrode as rapidly on the outside in regions with alkaline (limey) soil as in damp regions with acidic soil.

Temperature also plays an important role in corrosion rate. Prevention of corrosion therefore depends on the formation of a suitable protective layer. Some metals are more resistant to corrosion than others.

Many of these metals form a protective coating (layer) around the metal to protect it against corrosion. Examples are: alloys (e.g. manganese bronze and aluminium bronze), aluminium, chrome, gold, copper (forming a resistance layer), lead, nickel, platinum, zinc and stainless steel.

15.3 Precautions against corrosion

The following precautions must be taken to prevent corrosion:

- Paint the object
- Apply oil, grease, vaseline or lard
- Metal coating. Hot dipping - dip mild steel into molten zinc to produce galvanised steel
- Electroplating
- Spraying coatings such as tin, copper, aluminium, etc. onto base metals
- Non-metallic coating: anodising, chromating, etc.

15.4 Cathodic protection

There are basically two methods of applying cathodic protection to metal in contact with soil or water.

15.4.1 Galvanic

A metal which is less noble than the metal to be protected is chosen as protective layer. Magnesium, zinc or aluminium is used to protect steel, cast iron and copper. Galvanic protection is usually a cheap method.

15.4.2 Impressed current

This method is more adaptable to different purposes than is the galvanic protection method. Impressed currents are advantageous when long term protection is required.

The basic operating principle is the same as in (a) except that in this case energy is supplied from an external source.

15.5 Stabilisation of water

After disinfection, water needs to be stabilised to protect distribution systems. Any water will, given time, corrode a clean surface of iron, other metals or even concrete. Depending on many factors, all wastes are corrosive or scale forming.

If it is corrosive it leads to pipes leaking and corrosion of valves and tanks. If it is excessive scale forming, the scale tends to block boiler tubes, heat exchangers, hot water systems and even domestic kettles.

The type of water aimed at should be one that forms a slight incorrodable scale. Softening of water is usually achieved by addition of lime.

By determining the saturation index, the properties of a watersource (and the amount of lime to be added) can be determined as corrosive or scaleforming.

The saturation index and Ryznar index depend on the ratio between the pH, temperature, total dissolved solids, alkalinity and calcium hardness.

By doing the various tests on a water sample and by using the values obtained, the pH can be determined by using various tables designed for this purpose.

Table 15.1 (TDS), **Table 15.2** (temperature), **Table 15.3** (calcium hardness), **Table 15.4** (Total alkalinity) and **Table 15.5** (properties of water) will provide you with valuable information when dealing with the stabilisation of water.

mg/l TDS	Factor
50	0,07
75	0,08
100	0,10
150	0,11
200	0,13
300	0,14
400	0,16
600	0,18
800	0,19
1000	0,20
2000	0,40

Table 15.1 TDS

°C	°F	Factor
10	50	2,34
12	54	2,28
14	58	2,22
16	61	2,20
18	64	2,14
20	68	2,10
22	73	2,04
24	75	2,00
26	79	1,97
28	82	1,92
30	86	1,88
32	90	1,84
34	93	1,81
36	97	1,77
40	104	1,71
45	111	1,63
50	122	1,55

Table 15.2 Temperature

mg/l	Factor
4	0,20
6	0,38
8	0,51
10	0,60
15	0,78
20	0,90
25	1,00
30	1,08
40	1,20
50	1,30
60	1,38
70	1,45
80	1,51
90	1,56
100	1,60
110	1,64
120	1,68
130	1,72
140	1,75
150	1,78
160	1,81
170	1,83
180	1,86
190	1,88
200	1,90
300	2,08
400	2,20
500	2,30

Table 15.3 Calcium hardness

mg/l	Factor
4	0,60
6	0,78
8	0,90
10	1,00
15	1,18
20	1,30
25	1,40
30	1,48
40	1,60
50	1,70
60	1,78
70	1,85
80	1,90
90	1,95
100	2,00
110	2,04
120	2,08
130	2,11
140	2,15
150	2,18
160	2,20
170	2,23
180	2,26
190	2,28
200	2,30
300	2,48
400	2,60
500	2,70

Table 15.4 Total alkalinity

Byznar stability index	Property of water
4,0 to 5,0 5,0 to 6,0	Strongly scale forming Scale forming
6,0 to 6,5 6,5 to 7,0	Slightly scale forming Slightly corrosive
7,0 to 7,5 7,5 to 9,0	Corrosive Highly corrosive

Table 15.5 Properties of water

15.5.1 Calculating the stability of pH (pHs)

$pHs = (9{,}3 + A + B) - (C - D)$

(The values A - D are obtained from the tables: A = **Table 15.1**; B = **Table 15.2**; C = **Table 15.3**; D = **Table 15.4**)

Calculating the saturation (Langelier) index:
Langelier index = pH – pHs

- If the index is zero: - water is in equilibrium
- If the index is positive: - water has scale forming properties
- If the index is negative: - water has corrosive properties

Worked Example 15.1

Water with a pH of 7,8 has the following properties:
TDS 300 mg/l = 0,14 (**Table 15.1**)

Temperature 30°C = 1,88 (**Table 15.2**)
Ca hardness 80 mg/l = 1,51 (**Table 15.3**)
Alkalinity as CaCo3 60 mg/l = 1,78 (**Table 15.4**)

$$\begin{aligned} pHs &= (9{,}3 + 0{,}14 + 1{,}88) - (1{,}45 - 1{,}70) \\ &= 11{,}32 - 3{,}15 \\ &= 8{,}17 \\ &= 8{,}20 \end{aligned}$$

$$\begin{aligned} Saturation\ index &= pH - pHs \\ &= 7{,}8 - 8{,}2 \\ &= -0{,}4 \end{aligned}$$

15.5.2 Calculating the stability (Ryznar) index

Ryznar index = 2 pHs – pH

Worked Example 15.1

Water with a pH of 7,8 has the following properties:
TDS 300 mg/l = 0,14 (**Table 15.1**)

Temperature 30°C = 1,88 (**Table 15.2**)
Ca hardness 80 mg/l = 1,51 (**Table 15.3**)
Alkalinity as CaCo3 60 mg/l = 1,78 (**Table 15.4**)

$$\begin{aligned} pHs &= (9{,}3 + 0{,}14 + 1{,}88) - (1{,}45 - 1{,}70) \\ &= 11{,}32 - 3{,}15 \\ &= 8{,}17 \\ &= 8{,}20 \end{aligned}$$

$$\begin{aligned} Ryznar\ index &= 2\,pHs - pH \\ &= (2 \times 8{,}2) - 7{,}8 \\ &= 8{,}6 \end{aligned}$$

According to this value, water is highly corrosive. The Ryznar index provides a more reliable indication of the scale forming or corrosive properties of water than the Langelier index.

15.5.3 Corrective measures

Add lime to neutralise the acidity of water to protect pipelines and equipment.

15.5.4 Corrosivity ratio

The ratio is calculated as follows:

$$\frac{mmol/l\ Cl^{-} + 2(mmol/l\ SO_4{}^{=})}{mmol/l\ \ alkalinity\ as\ CaCO_3}$$

If the value obtained is less than 0,2 the water will not have corrosive properties. Increasingly higher values indicate increasing corrosivity. Chlorides and sulphates cannot be economically removed from water.

The alkalinity could well be increased to lower the ratio of chlorides and sulphates to alkalinity, but in many cases it would have to be increased by an impractical amount making the mineral content of water unacceptable.

In most cases the treatment at the purification works can be adapted to prevent the further increase of the corrosivity ratio. Where alum or $FeC1_3$ is used as flocculant, their use should be reduced to a minimum by adding flocculant aids such as polyelectrolytes, floccotan, etc.

This prevents the chloride- and sulphate ion concentration in the water from increasing which in turn would increase the corrosivity ratio.

It is thus more practical to control the corrosivity of water by applying the Langelier or Ryznar stability index, where the alkalinity and calcium can be controlled, than it would be to apply the corrosivity ratio.

15.6 Maintenance

Extensive distribution systems are needed to deliver water to individual consumers in the required quantity and under satisfactory pressure. The distribution system is often the major investment of a municipal works.

Therefore it is absolutely necessary to maintain it in excellent condition. Good system design ensures the minimum maintenance easily carried out on a regular basis. Periodic cleaning and sterilising is essential to ensure consistency of water quality at the point of use.

The hydraulic efficiency of pipes will diminish with time because of encrustation and sediment deposits. Flushing will dislodge some of the foreign matter, but to clean a pipe effectively, a scraper must be run through it.

This process may be costly, but may pay off with increased hydraulic efficiency and increased pressures throughout the system.

15.7 Sampling at various points for residual chlorine and bacteria

The major part of quality control is testing water in the distribution system for chlorine residual. Effectiveness of the disinfection process is determined by testing for the coli form group of bacteria as indicators for water quality.

Water samples should be taken at reservoirs and points along the distribution network, on a regular basis, for analysis.

15.8 Shock disinfection after repairs

A new main after installation should be flushed to remove all dirt and foreign matter and be disinfected.

The chlorinated water should remain in the pipe for a minimum of 24 hours while all valves and hydrants along the main are operated to ensure their disinfection.

At the end of this period, no less than 25 mg/l chlorine residual should be remaining. Another method is to dose at 300 mg/l for a period of at least 3 hours. Flush the chlorinated water now with potable water and do microbial tests before placing the main in service.

A broken pipeline is isolated, repaired, flushed and disinfected as in the procedure described for new mains. Tanks and reservoirs are also disinfected after placed into service or following inspection and cleaning.

Chlorine can be added directly to filling water or the walls and other surfaces may be sprayed with a solution containing ± 500 mg/l of available chlorine.

Activity 15.1

1. Name five measures which can be applied to prevent corrosion which is caused by the formation of an electric cell.
2. Answer:
   a. Name three indices which are used to determine the stability of water.
   b. Which variables are required to calculate these indices?
3. The Langelier index can either be positive, negative or zero. How would you interpret the answer in each of these cases?

4. What does it mean when water is said to be stable?
5. What is the formula for calculating the Ryznar index?
6. If the saturation pH of water is 8,5, up to which pH should the water be treated to give a Ryznar index at which this water would contain no corrosive properties.

Self-Check

I am able to:	**Yes**	**No**
• Describe corrosion and anti-corrosion measurements		
• Explain cathodic protection		
o Galvanic, impressed current		
• Describe stabilisation of water with regard to:		
o Corrosivity		
o scale formations		
o stability pH (pHs)		
o saturation (Langelier) index		
o stability (Ryzner) index		
o corrective measures		
o corrosivity ratio		
o chemical inhibitors		
o record keeping		
• Explain the maintenance processes		
• Describe sampling at various points for residual chlorine and bacteria		
• Describe shock disinfection after repairs		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module16

Special Treatment Processes

Learning Outcomes
On completion of this module, students should be able to:

- Describe softening
    - excess lime and lime-soda process
    - ion-exchange
- Describe nitrate removal
- Explain desalination
    - distillation (eg multi-effect evaporation)
    - reverse osmosis
    - electrodialysis
- Describe fluoridation
- Explain defluoridation

16.1 Introduction

This module serves as brief introduction to special treatment processes such as softening, desalination, fluoridation, etc. On completion of this module you should know the basics of these processes.

16.2 Softening

Softening of water is not essential to make water safe. The advantage lies chiefly in reducing soap consumption and lowering maintenance cost of plumbing fixtures.

The two basic methods for softening are the lime- soda process and ion-exchange process. The excess lime process is used in conjunction with flocculation to remove temporary and permanent hardness.

16.2.1 Lime- soda process

Lime ($Ca(OH)_2$) and soda-ash (Na_2CO_3) react with calcium and magnesium salts in water, to form insoluble precipitates ($CaCO_3$ and $Mg(OH)_2$) which can be removed by sedimentation. In addition lime treatment has the incidental benefits of bacterial action, removal of iron and aid in clarification of turbid waters.

The lime reduces the carbonate hardness and substitutes calcium salts for magnesium salts, while soda- ash acts on the non- carbonate hardness of calcium salts.

The sodium salts formed are soluble but not objectionable. Most of the $CaCO_3$ and $Mg(OH)_2$ precipitate will settle out in a sedimentation basin, but some will remain as fully divided particles and may be deposited on a filter or in pipes of the distribution system.

To prevent this, water should be re-carbonated by passing CO_2 gas through it as it leaves the sedimentation tank. In this process, insoluble carbonates combine with carbon dioxide to form soluble bicarbonates.

The amount of lime and soda required for softening depends on the chemical quality of water and the amount of hardness removal desired.

The major advantage is that lime added is removed along with the hardness taken out of solution. Thus the total dissolved solids in water are reduced. The lime-soda process has three distinct disadvantages:

1. large quantities of sludge is formed
2. careful operation is essential if good results are to be obtained
3. pipes will become encrusted if not properly recarbonated

After sedimentation and recarbonat ion, water is passed through a filter. Alum is often added with the lime and soda- ash to combine chemical coagulation and softening into a single process.

16.2.2 Ion exchange

The process is ideal where the TDS of influent does not exceed say 700 ppm. With correct resin choice and system layout, even organic contaminants can be removed. Techniques are available to produce treated water approaching theoretical H_20.

The common applications of ion exchange in water treatment are softening and removal of selective contaminants, such as the nitrate ion. An ion-exchange unit resembles a sand filter in which the medium is an ion- exchange resin rather than sand. Resins may be natural (zeolites) or synthetic.

As hardwater passes through the bed, the cations (Ca and Mg) are exchanged for sodium in the resin. Sodium salts formed are harmless. When a significant portion of the sodium in the resin has been replaced by Ca and Mg, it is regenerated with $NaCl$ solution.

Water passing through the bed during regeneration, must be washed as it contains large concentrations of chlorides. Ion- exchange units may be either gravity or pressure filters. The usual flow rate is $240\ l/min/m^2$.

As water passing through the filters contains no hardness salts and there is usually no need for such soft water, only a portion passing through the plant is softened and then mixed with un-softened water to obtain the desired effect.

One disadvantage of this method is that it results in increased concentrations of sodium that may be harmful to persons with heart trouble.

16.3 Anion exchange for nitrate removal

The most effective exchanger for nitrate removal is a strongly basic, anion resin that uses $NaCl$ for regeneration. All anion exchange resins preferentially remove divalent anions;' therefore, both sulphate and nitrate ions are removed and replaced by chloride ions.

This constitutes a major difficulty in processing water for nitrate removal, since many groundwaters contaminated with nitrate also have a significant sulphate concentration.

When the capacity for extracting nitrate ion is depleted, a regenerating solution with high salt content is passed through the bed to displace the sulphate and nitrate ions. The quality of waste brine from regeneration is about 5% of the water processed.

This amount varies with the sulphate content of the water being treated, and the exchange capacity of the resin, which decrease with usage. The major disadvantage of this process is high operating costs and the problem of brine disposal.

16.4 Desalination

Desalination of brackish water supplies and seawater can be very costly. Some of the processes for removing salts from water are: distillation, demineralisation, electrodialysis, reverse osmosis, etc.

Reverse osmosis and electrodialysis are used to desalt brackish groundwater or to reduce the concentration of contaminants such as nitrate and fluoride.

16.4.1 Distillation

Distillation is used for brackish and sea water from 5 000 ppm upwards, as from here it begins to look efficient and economical.

Recent research has been aimed at development of evaporators that would have minimum difficulty with scale formation. Estimates are that costs can be reduced by about one half of that with large dual- purpose plants, which generate high pressure steam for electric power and low pressure steam for evaporator operation.

16.4.2 Reverse osmosis

This is the favourite method for the treatment of raw waters from 700 ppm upwards and for brackish water from saline wells with high TDS and for sea water.

At the other end of the scale reverse osmosis may be useful where the TDS of raw water is low but organic contaminants are high. The end product contains between 5 and 107 of the original TDS, but organics are almost completely removed.

The process makes use of membranes which are selectively permeable to water. By applying very high pressures fresh water is pushed through membranes against natural osmotic pressure while leaving the salts behind.

Flow rates, through membranes depend upon initial salinity and vary between 0,8 m/d of seawater through 1,25 m/d for brackish waters.

16.4.3 Electrodialysis

Can be considered for brackish waters of up to 12 000 ppm to achieve an end product of potable water with a TDS of 200 ppm. Electrodialysis also serves as a pre-treatment process for ion-exchange plants.

By this method ions diffuse under the action of an electric potential through membranes that are selectively permeable to different types of ions. Because of extremely high cost, it is unsuitable for use with seawater.

16.5 Fluoridation

Fluoride in drinking water prevent dental caries and controlled fluoridation is an acceptable public health measure.

The 3 most commonly used fluoride compounds in water treatment are:

1. sodium fluoride
2. sodium silicofluoride
3. fluosilicic acid

Sodium fluoride, is the most expensive for the amount of available F, but is most widely used. This chemical is preferred if manual handling is involved, since the absence of fine powder results in a minimum of dust.

Fluosilicic acid is a colorless, transparent, fuming, corrosive liquid having a pungent odor and an irritating action on the skin. Sodium silica fluoride, the salt of fluosilicic acid, is the most widely used compound primarily because of its low cost.

The white, odorless crystalline powder is commercially available in various gradations for optimum application by various feeders. Fluoride must be injected at a point where all the water being treated, passes.

It can be applied in a channel, or main coming from the filters, or directly to the reservoir. Whenever possible, it should be added after filtration to avoid losses as a result with other chemicals.

Of particular concern is coagulation with heavy alum dosages and lime- soda softening. Fluoride injection points should be as far as possible from any chemical containing calcium so as to minimise loss by precipitation.

Surveillance of water fluoridation involves testing both the raw and treated water for fluoride and it should be the amount recommended by SABS 241 of 1984.

Records of the mass of chemicals and the volume of water treated should be kept to confirm that the correct amount is being added. The amount added to water should equal the quantity calculated from the increase in concentration and quantity of water treated.

16.6 Defluoridation

When water supplies contain excess fluorides the teeth of consumers become discoloured. Children drinking water containing 5 mg/l, developed fluorosis to the extent that the enamel is severely pitted, resulting in loss of teeth.

Treatment methods for de-fluoridation include using either activated alumina or bone char. Water is percolated through insoluble granular media to remove the fluorides.

The media are periodically regenerated by chemical treat treatment after becoming saturated with fluoride ion. Regenerating of bone char consists of backwashing with 1% solution of caustic soda and rinsing the bed.

Reactivation of alumina also involves backwashing with caustic soda.

Did you know?
Removal of excess fluoride from public water supplies is a sound economic investment when related to the increased cost of dental care and loss of teeth.

Activity 16.1

1. Explain what is meant by special treatment processes.

Self-Check		
I am able to:	**Yes**	**No**
• Describe softening		
o excess lime and lime-soda process		
o ion-exchange		
• Describe nitrate removal		
• Explain desalination		
o distillation (eg multi-effect evaporation)		
o reverse osmosis		
o electrodialysis		
• Describe fluoridation		
• Explain defluoridation		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 17

Sludge Treatment and Disposal

Learning Outcomes
On completion of this module, students should be able to:

- Describe sources of wastes in water treatment
- Explain dewatering
    - drying beds
    - lagooning
    - chemical treatment followed by mechanical filtration devices (pressure and vacuum)
    - centrifuging
- Describe water recovery
- Describe chemical recovery

17.1 Introduction

This module deals with different techniques to dewater sludge, formed in the purification process. It also includes the recovery of water and chemicals.

On completion you should have a good general knowledge of these processes.

17.2 Sources of wastes in water treatment

Wastes originate from chemical coagulation, precipitates from softening, filter backwash water, settled solids from pre-sedimentation, oxides from iron and manganese removal and spent brines from regeneration of ion-exchange units.

These wastes vary widely in composition, containing the concentrated materials removed from raw water and chemicals added in treatment. They are produced continuously and discharged intermittently.

Settled floccules are allowed to accumulate in clarifiers over relatively long periods of time, while backwashing of filters produces a high flow of wastewater for a few minutes, usually once a day for each filter.

17.3 Dewatering

17.3.1 Lagoons

Ponding is an acceptable method for dewatering, thickening and temporary storage of waste sludge. Drainage in lagoons may be improved by adding sand to the bottom or installation of under drains.

Clear water will overflow the weir. Sludge from water-softening plants are readily dewatered and yields about 50% solids. These solids can be removed by scrapers and used as landfill.

17.3.2 Drying beds

Sand drying beds are generally applicable to small water plants where land is readily available. Beds consist of 150 - 300 mm of coarse sand underlain by layers of graded sand. Beds are ± 0,6 to 1,5 m deep.

Dewatering action is essentially gravity drainage aided by air drying and decanting of supernatant. After a few months, the sludge cake formed on the surface is removed by shovels or by mechanical means.

17.3.3 Centrifuging

Centrifuging is used to dewater treatment plant sludge thickeners. The most popular centrifuge is drawn from settling tanks or gravity the solid bowl scroll type.

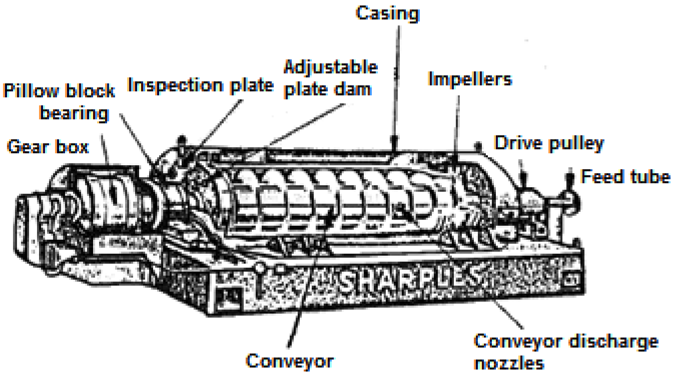


Figure 17.1 Solid bowl scroll type centrifuge

The unit consists of a rotating solid bowl in the shape of a cylinder, with a cone section on one end, and an interior rotating screw conveyor. Feed slurry, entering from the centre, is held against the bowl wall by centrifugal force.

Settled solids are removed by the conveyor while clarified effluent discharges at the other end. Removal of solids can be enhanced by adding polyelectrolytes or other coagulants with the slurry feed. The scroll centrifuge operates with little surveillance.

17.3.4 Pressure filters

The plate-and-frame filter press is the type of pressure filter adapted for dewatering of waste chemical sludge's. It consists of a series of recessed plates with cloth filters and interfering frames held together to form enclosed filter chambers.

These chambers are filled with dewatered solids by pumping in sludge under high pressure, forcing the water out through the cloth filters. At the end of the feed and pressure cycles, the plates are separated to remove the sludge cake.

Pressure filtration appears to be particularly advantageous for thickening alum sludge's where high solids content is most desirable.

17.3.5 Vacuum filtration

Not extensively used in water treatment. Based on studies, it appears that vacuum filtration will not receive broad application in dewatering of chemical sludge's since other processes seem to be more economical and achieve better results.

17.4 Water recovery

Supernatent overflowing, decanted or filtered through is recycled to the plant for treatment with incoming raw water.

17.5 Chemical recovery

Lime can be recovered from softening sludge's by re-calcination. The basic steps are gravity thickening, dewatering by centrifuging or pressure filtration after treatment to remove magnesium hydroxide and other impurities.

Definition: calcination
Reduce, oxidize, or desiccate by roasting or strong heat. Reduce, oxidize, or desiccate by roasting or strong heat.

Recalcining is accomplished by heating the dried solids in a rotary kiln or incinerator to produce lime and carbon dioxide.

Recovery of alum is rarely 'Practiced because of low- process efficiency and poor quality of the regenerated alum. The key problem is separation of aluminium hydroxide from other impurities in the waste sludge.

Where practiced, the sludge is mixed with sulphuric acid and discharged to a gravity thickener for separation of alum solution from settle-able insoluble residue.

Underflow from the thickener is wasted by treating with lime, dewatered and hauled away for landfill or burial.

Activity 17.1

1. Explain what is meant by lagooning.
2. Describe the processes used in water and chemical recovery.

Self-Check

I am able to:	Yes	No
• Describe sources of wastes in water treatment		
• Explain dewatering		
o drying beds		
o lagooning		
o chemical treatment followed by mechanical filtration devices (pressure and vacuum)		
o centrifuging		
• Describe water recovery		
• Describe chemical recovery		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Module 18

Occupational Hazards and Safety Measures

Learning Outcomes

On completion of this module, students should be able to:

- Explain the Factory Act and Regulations
- Describe hazardous chemicals and gases
- Describe fire and explosion hazards
- Describe colour coding for rapid identification
- Describe elementary first aid
- Describe ablution facilities
- Describe protective clothing

18.1 Introduction

This module serves as background knowledge to the Factory Act and Regulations, hazchem, first aid, colour coding, safety, etc. On completion you should have a general knowledge of these factors.

18.2 Occupation health and safety act and regulations (OHASA)

The primary object of the OHASA is to control working conditions in factories, which are applicable to water treatment works. This helps to prevent accidents and industrial diseases.

On large plants it is the responsibility of management to formulate and implement safety procedure. These must be actively supported by the operating and maintenance staff. On small plants the operator himself may have to take the initiative.

Employers must ensure that:

- machines are fitted with safeguards
- protective equipment and clothing are provided for workers
- workers are properly instructed on how to operate machines safely

- all persons visiting or employed do not smoke or use an open flame, except in those areas designated as safe

18.2.1 Instructions for employees

Employees need to perform the following tasks:

- wash hands well with soap and water after working with sludge and especially before eating,
- do not enter a manhole or sump without testing 'for hydrogen sulphide and wearing a harness attached to a rope held by a man at the surface,
- take care when standing or working over tanks and channels where there may be deep or swiftly moving water,
- never do a job unless you have enough help, the right tools and the necessary safety equipment,
- never use fingers to remove a heavy manhole cover or grate. Use the proper tools,
- lift with your legs, not your back, to prevent back strains,
- use all ladders carefully. Be sure that they do not slip or twist. Don't use metal ladders near electrical boards or equipment,
- never enter a manhole or any other pit below ground level when alone,
- always check manholes and any other pits below ground level for enough oxygen before entering,
- wear gloves when handling chemicals to prevent injury. Wear rubber gloves and boots when you are dealing with "live" electrical circuits,
- be sure that all guard rails and chains are properly installed and maintained,
- never enter a chlorine atmosphere when you are by yourself and without the proper protective equipment,
- be sure that walkways are kept clean,
- keep all chlorine containers secure so that they do not fall or roll,
- check over all chlorine connectors and lines before using. Replace any that appear defective.

All dangerous places should be securely fenced or otherwise adequately protected to prevent accidents. Employees also have responsibilities under the OHASA.

They must:

- use all safety equipment supplied to them
- not interfere with or abuse safety equipment
- do nothing wilfully to endanger the health and safety of himself and
- others
- obey orders issued in the interest of safety, either in the form of a
- general standing instruction or by his superior.

18.3 Hazardous chemicals and gases

18.3.1 Handling of coapressed gases (e.g. chlorine)

- Because of its shape, cylinders are awkward to carry. They may be rolled but never dragged.
- Never lift cylinders by means of electro-magnets or by slings. A purpose-made cage or platform should be used when cylinders are to be raised by crane.
- Do not use cylinders as rollers, supports, anvils or any purpose other than that for which they were designed.
- Do not tamper with the safety devices embodied in the valves.
- Prevent the cylinders from falling or bumping heavily against each other.
- Use chalk to mark empty cylinders as "empty" or "MT". Close valves and replace protective caps.
- Always handle cylinders as if they are full.
- Store in a well-ventilated area away from heat or direct sunlight.

18.4 Fire and explosion hazards

The 3 elements which must be present in any fire is oxygen, heat and fuel, see **Figure 18.1** below. Remove any of these and the fire will be extinguished

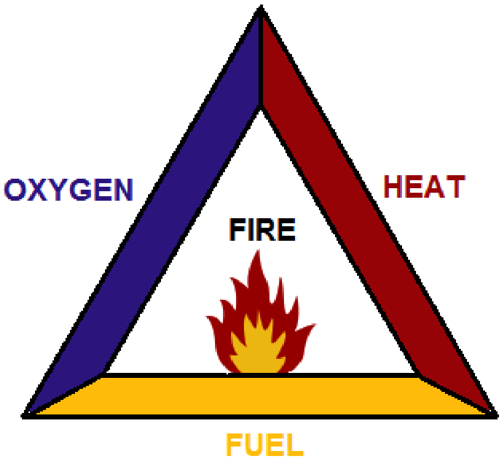


Figure 18.1 Fire triangle

The main causes of fire are:

- faulty electricity
- open flames
- heated surfaces
- matches and cigarettes
- spontaneous ignition
- chemical reactions
- static 'electricity
- friction
- lightning

Fire can be classified into the following 4 classes, see **Figure 18.2**:

18.4.1 Class A

Wood, paper, etc. are used as fuel. Here a soda-acid extinguisher can be used, but the modern trend is to use gas propelled water.

18.4.2 Class B

Flammable liquids are the fuel. Here a dry foam, dry chemical or CO_2 type of extinguisher can be used.

18.4.3 Class C

Electrical fires: A CO_2 or dry chemical type of fire extinguisher can be used.

18.4.4 Class D

Flammable metal fires; i.e. magnesium, lithium, potassium. Special chemicals, iron filings and French chalk can be used as extinguishers.

A - **Common combustibles e.g wood, paper etc.**

B - **Flammable liquids and gases e.g gasoline, propane etc.**

C - **Live electrical equipment e.g computers etc.**

D - **Combustible metals e.g titanium etc.**

Figure 18.2 Fire classification

Extinguishers should be placed close to likely fire hazard but not so close that they can be damaged or cut off from sudden fires.

They should be located outside entrances to danger areas, never inside where they may be inaccessible (at conspicuous places).

If hung from large columns or posts, distinguishing red bands can be painted around the posts or red discs or arrows can be painted on the wall above the extinguishers.

18.5 Colour coding for rapid identification

Identifying machinery and different machine parts by coded colours helps people to recognise them quickly. It also gives ready warning of danger and helps to reduce industrial accidents.

It is really a supplement to machine guarding and other methods of eliminating hazardous conditions and triggers off a spontaneous reaction by workers in emergencies.

To indicate the general nature of their contents, pipes should be marked with a basic colour over their entire length or at strategically placed intervals.

Distinguishing bands of colour are superimposed on the basic colour to identify the specific nature of the content, e.g. the basic colour of water is green. Cornflour (blue) bands superimposed on this colour signify drinkable water, whereas verdigris bands indicate non-drinkable water.

Gases are indicated by a light stone colour, CO_2 by light stone with a grey band, O_2-light stone with a white band, etc.

The following colours are used for safety identification:

- **Red**

Red is the basic or background colour used alone or in conjunction with white lettering stripes to indicate danger, fire protection equipment, stop buttons and emergency stop controls.

- **Examples include:**
  - Danger: barricades prohibiting passage of persons.
  - Fire protection equipment: fire alarms and boxes, fire buckets, position of equipment.
  - Stop buttons and emergency stop controls: electrical stop buttons, emergency stop bars.

- **Yellow**

Yellow is the basic or background colour used alone or in conjunction with black to indicate places where caution should be exercised or places where warnings of hazards are required.

- **Examples include:**
  - markings at barricades, temporary constructions or mobile equipment
  - low headroom owing to structures
  - changes in floor level and other tripping hazards
  - demarcation on floor for stacking, walkways and fire extinguishers.

- **Green**

Green is used in conjunction with white lettering to indicate safety and first-aid equipment. Green is also in the colour for starting buttons on machines.

- **Examples include:**
  - location of first aid facilities
  - location of gas masks

- exit signs other than emergency exits
- safety instruction signs
- safe areas
- packing areas
- equipment storage
- toilets
- offices
- entrances, etc.

- **Light orange**

Light orange is used on the inside surfaces of machine guards as well as dangerous parts of a machine capable of cutting, shearing or crushing, the surfaces of protruding shafts, the faces of gear wheels and any rotating part of a machine.

The intention is to draw immediate attention to hazard presented because a guard has been removed. This colour is also to be used for identification of all electrical switchgear, electrical service conduits and allied fittings, but not on electric motors.

18.6 Elementary First Aid

The next best thing to preventing accidents and disease, is prompt and skilled first- aid.

Management must provide an adequate stocked first-aid box if it employs five or more people. A qualified first-aider must be employed for staffs of ten or more. A separate properly first- aid room must' be provided where 100 or more people are employed.

A notice should be displayed where and in whose care the box is kept, and the user must ensure that he is notified immediately of all accidents. The first-aider is required to render prompt first-aid to any injured person.

- **First-aid benefits employees because:**
  - it cuts time away from work due to injuries and illness
  - it reduces disablement and disruption of production
  - develops a team spirit among the workers trained in first-aid
  - makes workers safety conscious.

- **First-aid knowledge benefits workers because:**
  - it gives them valuable knowledge to be used both at work and at home
  - it save lives and reduces pain and disability
  - increases their usefulness to others, giving workers added esteem in the eyes of others.

18.7 Ablution facilities

According to legal requirements:

- Every works manager shall provide and maintain sufficient and suitable latrine facilities of a high hygienic standard.
- Where the number of persons employed is 100 or less, there shall be one latrine for every 25 persons or portion thereof.
- Latrines shall be so arranged as to be conveniently accessible to all persons and within a reasonable distance of any working place. Where the work is of a temporary nature, portable toilets proportional to the number of persons employed at such places, shall be provided.

18.8 Protective clothing

According to the Occupation Health and Safety Act (formerly Machinery and Occupational Safety Act), the following apply for protective clothing and appliances:

- **Regulation 2-7: Some of the most important points are:**
- The user is required to supply and maintain in good order, adequate protective clothing and appliances wherever the nature of the work being done or the process requires the protection of the worker against specific hazards or materials or where the workers' clothes could be damaged by corrosive or other injurious substances.
- protective equipment supplied by the user must be used by the worker
- states that no jewellery or loose-fitting over clothing or ornaments may be worn near moving machinery

All those employed on the works should have the following basic protective clothing:

- hardhat
- overall
- gumboots and safety boots
- gloves
- oilskins

For those employed in workshop activities:

In addition to the abovementioned:

- Earmuffs
- Appropriate goggles, gauntlets, etc. for use during welding, grinding and cutting
- Workshop gloves (soft flexible leather with fingertip and knuckle protection) for general work

For those employed in laboratory work:

- Acid resistant dustcoats
- Unlined neoprene gloves
- Safety glasses

Activity 18.1

1. Explain why it is necessary to adhere to the Factory Act and Regulations.
2. Describe colour coding that is used for identification.
3. Describe the dangers of fire and hazardous chemicals.

Self-Check

I am able to:	**Yes**	**No**
• Explain the Factory Act and Regulations		
• Describe hazardous chemicals and gases		
• Describe fire and explosion hazards		
• Describe colour coding for rapid identification		
• Describe elementary first aid		
• Describe ablution facilities		
• Describe protective clothing		

If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.

Module 19

Process Control, Record Keeping and Practical

Learning Outcomes

On completion of this module, students should be able to:

- Explain minimum control analysis:
    - analysis required
    - reasons for analysis
- Describe elementary laboratory procedures and practice
- Explain the use of standard solutions
- Describe sampling procedures
    - frequency of sampling and analysis with interpretation of results
    - Brief introduction to bacteriological analysis
- Describe and maintain record keeping

19.1 Introduction

In this module the purpose and methods of sampling as well as elementary control tests will be discussed.

On completion of this module, you should be able to describe sampling procedures, elementary laboratory procedures and practice, elementary control tests and reasons for records.

19.2 Minimum control analysis

It is essential to know how well a water purification plant is operating. A check should be kept on colour, pH, turbidity, etc.

Check tests are done to determine the functioning of different units as well as purified water leaving the plant. Because of legislation controlling the quality.

It is therefore also important to know the parameters set for potable water (Refer to module 9 for specifications).

19.3 Use of standard solutions

Any solution the exact concentration of which is known is a standard solution. A standard solution may be prepared by either of two methods:

19.3.1 Direct method

An exactly weighed amount of solute, of definite and known composition, is dissolved and made up to known volume in a volumetric flask; from the known weight and volume, the concentration is calculated. The solute in this case must be a primary standard substance.

This method is especially convenient for the preparation of a standard solution of a pre-determined concentration, such as a solution that is exactly 0,10 N, or a solution that has an exact titer in terms of a specified desired constituent that is to be determined, e.g. an iron titer of 5,00 mg/ml.

19.3.2 Indirect method

Many of the solutes required as titrants are not available as primary standards, so these solutions cannot be prepared by the direct method.

A solution of the approximate concentration is made with only rough measurements of weight and volume; the solution is then standardised by measuring accurately the volume of this solution required to titrate an exactly weighed amount of primary standard.

The exact concentration is then calculated from the volume of solution used, the weight of the primary standard, and its equivalent weight in the titration reaction.

19.4 Sampling procedures

Adequate sample should be provided for all analysis, namely a minimum of 2 liters for chemical analysis, 250 ml for bacteriological analysis on potable water and 100 ml for analysis on effluent samples. Use suitable bottles with close-fitting clean stoppers. Clean the bottles thoroughly before use.

If a sample is to be analysed after more than six hours from the time of sampling (24h for cooled samples), carry out the examination but state on the report that because of the delay in commencement the examination does not comply with the requirements of the specification and that the results should be evaluated accordingly.

Samples that are more than 24h old may be tested only for the presence or absence of feacal coliform bacteria. State on the report of the result of the test that because of the delay in commencement the examination does not comply with the requirements of the specification.

Do not test any sample older than 48h. In the case of any examination commenced more than 6h (24h for cooled samples) after sampling, the results obtained are not to be used to assess compliance or non-compliance with the requirements of the specification. Such results may be used only for purposes of information.

19.4.1 Samples for bacteriological analysis

Ensure that the points where the samples are taken are such that it is as representative as possible of the water throughout the storage and reticulation system. Samples should be taken as follows:

- **Tap water**

Samples should not be taken from dead ends or leaking taps. Allow the tap to run long enough to ensure that the sample comes from the main pipeline. In some cases it may be necessary to heat the tap with a gas flame before opening it.

Reduce the flow from the tap so that the water does not splash when the bottle is placed below it. To avoid contamination, remove the lid with one hand (do not put it down) and take the sample with the other.

Hold the bottle more or less in the middle so that your fingers do not come into contact with the mouth of the bottle. Rinse the bottle at least three times with sample to be collected, fill and replace the lid immediately.

Ensure that the bottle is properly marked. Also ensure that the bottle is not over full so that the analyst can shake the bottle to obtain a representative sample,

- **Dam or river water**

Samples taken from a river should be collected upstream. Ensure that your fingers do not come into contact with the mouth of the bottle. If collected from a dam, put your arm one cubit under the water and collect the sample.

Rinse bottle at least 3 times and then collect sample (not over full) to allow analyst to shake the bottle to obtain a representative sample.

19.4.2 Sample taking for chemical analysis

The results of an analysis done at a certain time of the year may differ markedly from those done at a different time of year. Therefore it is recommended that samples are taken four times per year for a complete analysis.

The following times are recommended: the rainy season, the end of the rainy season, approximately the middle of the dry season and just before the rainy season. Collect the samples in glass bottles of about 2 liter capacity with well fitting, clean lids.

Protect the lid and neck by winding a cloth or piece of paper around it. Rinse the bottle thoroughly three times with the sample to be collected, shaking it well and drain it.

When sampling from a pipeline, the tap should run at least 2 minutes before the sample is collected. The flow from the tap should be reduced while the sample is taken to prevent oxidation of the sample.

When sampling from new boreholes, the pump should be allowed to run for about 30 minutes before the sample is taken. For boreholes in use, about 5 minutes would be adequate.

Samples from running water (stream or river) should be taken in the stream with the neck of the bottle against the stream. When the sampler stands upstream of the bottle, he must ensure that he does not collect disturbed water.

As mentioned earlier, samples should be analysed as soon as possible to prevent any chemical change after a few minutes due to a loss of CO_2, O_2, chlorine or H_2S. For this reason temperature, pH and dissolved gases should be determined immediately after the sample is taken.

With a change in the pH-alkalinity-carbon dioxide balance, calcium carbonate can precipitate with a resultant decrease in the calcium and total hardness values.

19.4.3 Information to be supplied when samples are submitted for testing:

The following information (as relevant and given as fully as possible) should accompany each sample submitted for testing:

- the name and address of the organisation or person requesting the tests
- the type of testing required (biological or chemical or both)
- date and time of sampling
- date and time when sample was dispatched
- name of the sampler
- description of the sampling point i.e. storage container (reservoir, tank, etc.), the well, borehole, spring or stream, as relevant
- date when last rain occurred and whether or not it was heavy
- whether the water had any odor or taste that was considered objectionable
- approximate number of persons receiving the supplied sample
- whether the source of the sample had been treated or not

19.5 Frequency of sampling analysis and interpretation of results

As already mentioned, samples should be taken at least four times per year on points along the distribution system and reservoirs. The following tests are the minimum to be done for effective control over quality of potable water:

Note:
Unless otherwise stated, use only analytical grade reagents and distilled water for analysis.

19.5.1 Colour

Colour in natural water can be the result of metal ions such as iron or manganese present in water or it can be of organic origin or due to pollution. It is necessary to remove colour to make water aesthetically acceptable for general use.

True colour of water is considered to be only that attributable to substances in solution after removal of suspended materials by centrifuging or filtration.

Colour is determined on a clear sample by visually comparing it with a standard coloured solution of known concentration. Calibrated coloured discs can be used instead of the standard solution, and is expressed in Hazen units.

Discs are calibrated from 5 to 20 Hazen units, in increments of 5. If the color falls outside this range, it must be diluted to bring it within range. The result obtained must be multiplied by the dilution factor and expressed to the nearest 5.

One Hazen unit represent the colour occurring when 1 mg platinum is dissolved in 1 liter of water. The colour of purified water should not exceed 20 Hazen units and should preferably be less than 5 Hazen units.

19.5.2 Turbidity

Insoluble particles of soil, organics, micro-organisms and other materials impede the passage of light through water by scattering and absorbing the rays. This interference of light passage through water is referred to as turbidity.

Turbidity should be determined once the water has been allowed to settle for 1 hour. A sample should be draw from the upper portion without disturbing the sediment.

Turbidity is expressed as nephelometric turbidity units (NTU) and is determined by means of a nephelometer. Sample tubes should be kept clean and free of scratch marks. Cover the sample tube with the light screen before taking a reading.

As the turbidity of treated water is a good measure of the efficiency of the purification process, a turbidity of 1 NTU should be aimed at.

19.5.3 pH

The pH value is a measure of the intensity of acidity or alkalinity of water. It does not reflect the total concentration of acid or alkali present. The following is the pH scale as shown in **Figure 19.1**:

Figure 19.1 pH scale

Water with a pH of less than 6 corrodes metals. It may be remedied by decreasing the acidity by addition of lime or sodium carbonate. A pH value of more than 7 indicates that water is alkaline. The alkalinity of natural waters is mainly due to dissolved bicarbonates.

pH is determined by means of a pH meter (electrometrically) or by means of special indicator papers and - solutions. The pH meter is standardised against buffer solutions (e.g. pH 9, 7 and 4) before measuring samples. The electrodes are then rinsed with distilled water.

The use of indicator paper and solutions are limited to clear water samples where high accuracy is not needed.

- **Care of pH electrodes**
  - When not in use, certain electrodes should be kept in a slightly acidic buffer solution (pH4) or in distilled water. Adhere at all times to manufacturers instructions.
  - Buffer solutions should not be used if they become turbid or if algal growth occurs. A fresh solution must then be obtained.
  - Calomel reference electrodes are filled with a saturated potassium chloride (KCl) solution.
  - Combined electrodes are filled with a 3 molar KCl solution.
  - Remove all deposits with a weak solution of soap and dry with tissue paper.
  - Rinse with distilled water and dry with tissue paper.

19.5.4 Electrical conductivity

Conductivity is generally proportional to the concentration of total dissolved solids. The conversion factor is ± 6,6, but may differ from one water to the next.

Conductivity is expressed in mS/m and is determined on a conductivity meter. Rinse the cell with water, place sample in cell and place probe in sample. Remove all air bubbles. The cell must be rinsed with distilled water between readings and after it has been used.

19.5.5 Total dissolved solids

The IDS may be determined by approximation by calculating the electrical conductivity by the factor 6,6.

Total dissolved solids, the total residue on evaporation, is the term applied to material left in a porcelain dish after evaporation and drying in an oven.

A measured filtered sample is placed in an evaporating dish, and weighed. After evaporation on a steam bath, the dish is transferred to an oven (103 °C) for drying and weighed again.

The milligrams of total residue are equal to the difference between the cooled weight of the dish and the original weight of the empty dish. **Table 19.1** is an interpretation of salinity

TDS (mg/l	Type
< 1 000	Fresh
1 000 to 5 000	Mildly brackish
5 000 to 15 000	Moderately brackish
15 000 to 35 000	Very brackish
> 35 000	Sea water

Table 19.1 An interpretation of salinity

19.5.6 Alkalinity

Alkalinity of natural waters is due to the presence of salts of weak acids and is defined as the capacity of the solution to neutralise acid. Alkalinity is mainly due to the presence of bicarbonates and carbonates.

Water is titrated against a standard acid solution (10 mmol/l H_2SO_4) in a calibrated burette to dispense it. Endpoint of titration is determined by addition of a colorimetric indicator.

The pH value of importance in this case is 8,3 (phenolpthalein alkalinity) and pH 4,6 (methyl orange or total alkalinity).

In certain water purification processes (e.g. lime softening), it is sometimes necessary to distinguish between the different forms of alkalinity. The pH ranges in which these various forms of alkalinity occur may be represented as follows in **Table 19.2**:

0 - 46	4,4 – 8,3	8,3 – 9,4	9,4 – 14,0
Mineral acids	Bicarbonate Alkalinity, CO_2	Carbonate and Bicarbonate alkalinity	Hydroxide and Carbonate Alkalinity

Table 19.2 pH range

As indicated, bicarbonate and hydroxide are not found in solution together. Whenever a sample is titated with a standard acid, the phenolpthalein alkalinity is shown as "P".

The methyl orange alkalinity or total alkalinity as "T". The various forms of alkalinity may be calculated from **Table 19.3** below:

P = 0	P < ½ T	P = ½ T	P = >1/2 T	P = T
Bicarbonate Alkaline	Carbonate + Bicarbonate Alkaline	Carbonate Alkaline	Carbonate + Hydroxide Alkaline	Hydroxide Alkaline
$HCO_3 - Alk = T$	$CO_3 - Alk = 2P$ $HCO_3 - Alk = T - 2P$	$CO_3 - Alk = 2P$	$OH - Alk = 2P - T$ $CO_3 - Alk = 2(T - P)$	$OH - Alk = P$

Table 19.3 Alkalinity

All alkalinities are expressed of an equivalent quantity of $CaCO_3$ in mg/l. To do the total alkalinity test, a suitable sample (100 ml or 50 ml) is taken to give a titration of no more than 20 ml.

Add 1 to 2 drops of methyl orange and titrate until it becomes pink. Just before the endpoint is reached rinse the sides of the Erienmeyer flask with distilled water from a wash bottle. Alkalinity is now calculated as follows:

Alkalinity as mg/l

$$CaCO_3 = \frac{ml\ acid \times 1000}{ml\ sample}$$

19.5.7 Total hardness

Hardness is caused by metallic cations, calcium and magnesium. Water is titrated against a standard solution EDTA. The reading on the burette is used to calculate the total hardness in water.

Experiment 1

Use a suitable sample (50 ml - 100 ml) to give a titration of ± 10 ml EDTA. Place sample in an Erlenmeyer flask and add 2 ml ammonium chloride buffer to obtain a pH of 10,0 to 10,01.

Also add 1 - 2 drops of Eriochrome black T. Fill the burette with10 mmol/l EDTA. Carry out titration by slowly adding EDTA to sample while shaking the flask.

When near to the endpoint, rinse the sides of the flask with distilled water from a wash bottle. Slowly titrate to the endpoint. The colour changes from wine red to bright blue.

Total hardness can now be calculated as follows:

$$Total\ hardness\ (as\ mg/l\ CaCO_3)\ =\frac{Titration\ \times 1\,000}{ml\ sample}$$

19.5.8 Calcium hardness

Experiment 2

Take a suitable sample in an Erlenmeyer flask and dilute if required to ± 100 ml. Add 2 ml NaOH buffer solution. The pH mst be greater than 11,0. Add a pinch of mixed indicater (murexide).

Shake well and titrate against 10 mmol/l EDTA until the colour changes from red to blue.

A control sample of distilled water and the same quantity of reagents will aid in seeing the endpoint more easily. The amount of calcium hardness as mg/ l $CaCO_3$ can be calculated as follows:

$$=\frac{Titration\ \times\ 1\,000}{ml\ sample}$$

- **Interpretation of results**

  - **Degree of hardness**
    - Soft
    - Reasonably soft
    - Slightly hard
    - Reasonably hard

- Hard
- Very hard

- **Total hardness as mg/l $CaCO_3$**
- Less than 50
- 50 to 100
- 100 to 150
- 150 to 250
- 250 to 350
- more than 250

If the values obtained for alkalinity and total hardness are more or less the same, the hardness present is mainly temporary hardness. A value greater than 200 mg/l indicates that serious scale formation will occur in hot water systems.

Note:
If the alkalinity is less than the total hardness, the difference is due to permanent hardness.

19.5.9 Free and residual chlorine

Generally determined by the DPD method and Lovibond comparator. Allow at least 30 minutes contact time after dosing, before doing the test. One DPD no 1 tablet is used per test by adding it to the glass tube together with 10 ml sample (a pink colour develops).

The tube is then placed in the right hand aperture with a control tube containing only the sample in the left hand aperture.

The disc is rotated until the colour matches that of a sample. The reading is given directly in mg/l Cl_2. By using DPD tablet no 4, the total residual chlorine can be determined, ie both the free and bonded residual chlorine.

19.5.10 Stabilisation tests

The following tests needs to be done in order to calculate stabilization indices (pHs, Langelier and Ryznar).

- Temperature which is measured with a calibrated thermometer
- pH which is measured with a pH meter
- Total dissolved solids
- Total and calcium hardness
- Alkalinity

- **Stability pH (pHs)**

This is the calculated pH value at which a water sample will be in equilibrium with calcium carbonate, without a change in total alkalinity and calcium concentration.

The pHs may also be defined as the calculated pH value at which, by addition or removal of CO_2, a water sample will be in equilibrium with calcium carbonate. The pHs value for a given water sample may be calculated by using the Langelier stability tables.

$$pHs = (9{,}3 + A + B) - (C + D)$$

(Refer to Langelier stability **Tables 15.1 – 15.4** module 15)

- **Saturation index (Langelier index)**

The Langelier index is given by pH - pHs. This value gives an indication of stability with respect to $CaCO_3$ precipitation (scaling) or dissolution.

A positive value indicates a tendency to precipitate $CaCO_3$, while a negative value is an indication that $CaCO_3$ may dissolve.

These values are not quantitative, ie the magnitude of the figure does not reflect the degree of corrosion or scaling properties of water.

- **Stability index (Ryznar)**

The Ryznar index is given by 2 pHs - pH. This value is positive for all waters. A water with an index greater than 7 indicates that scaling is not likely to values greater than 7, 5 indicate corrosive properties or tendencies.

These values are quantitative; thus values greater than 10 and higher may indicate serious corrosive properties. Interpretation: in some cases conflicting results may be obtained using the Langelier and Ryznar indices (see **Table 19.4**). Conflicting results should be reported as such.

Ryznar index	Property
$\leq$ 60	Excessive scale forming
6,0 - 6,5	Slightly scale forming
6,5 - 7,5	Stable
7,5- 8,5	Slightly corrosive
> 8,5	Highly corrosive

Table 19.4 Ryznar index

- **Corrosivity ratio**

In the pH range 7 to 8 and in the presence of dissolved oxygen, ratios $\leq$ 0,1 indicate general freedom from corrosion. Increasing values indicate increasing corrosivity.

19.5.11 Flocculation tests (jar tests)

Efficient coagulation and flocculation is influenced by the following factors: temperature, turbidity, colour, pH, alkalinity, time, effectiveness of mixing, agitation during floc formation and characteristics of coagulant being used.

When a new watersource must be developed, the only way to determine the dosages needed is by doing jar tests in the laboratory. This also holds when a sudden change in the quality of an existing watersource occurs.

Effectiveness of chemical coagulation of water can be experimentally evaluated in the laboratory oy using a 6 paddle stirrer. After rapid mixing to disperse the chemicals, the samples are stirred slowly for floc formation and are then allowed to settle under quiescent conditions.

The jars are mixed at a speed of 60 to 80 rpm for 1 minute after the addition of the coagulant solution and are then stirred at a speed of 30 rpm for 15 minutes.

After the stirrer is stopped, the nature and settling characteristics of the floc are observed and recorded in quantative terms, as poor, fair, good or excellent.

A hazy sample indicates poor coagulation, while properly coagulated water contains floc that are well formed with the liquid clear between particles.

After 30 minutes a sample should be pipetted from the surface water for colour and turbidity testing. The pH should be measured in the beakers themselves and the water filtered before chemical analysis are done.

Filter the samples through Whatman no 1 and determine the turbidity. A turbidity of less than 1 NTU indicates the correct dosage.

19.5.12 Chlorine demand

This is the amount of chlorine required to react with organic substances as well as other substances which may occur in the water. It is thus the difference between the amount of chlorine added and the residual chlorine after a certain contact period.

The chlorine demand varies according to the amount of chlorine added, the contact period and the temperature of the water. Turbid water and water containing algae, for example, will have a greater chlorine demand than clean water.

Chlorine demand is determined with a Loviband comparator and DPD tablets.
100 ml of sample is added to a series of 250 ml conical flasks. Add 0,5 ml standard chlorine solution to first flask, 1,0 ml to the second, etc. to others. Mix well to obtain dosages of 0,5; 1,0; 1,5 mg/l, etc.

Allow to stand for 30 minutes in a dark cupboard. Determine the concentration of free residual chlorine in each of the flasks by means of the DPD test.

The difference between the chlorine concentration as applied and the residual chlorine determined, is the demand. The demand will increase as the dosages increase.

19.6 Brief introduction to bacteriological analysis

Analyses are done to test for possible presence of pathogenic bacteria and effectiveness of chlorination process. Identification is of importance for the health risk associated with any given effluent.

Start the microbial examination within 6 hours (24h if cooled) of the time of sampling and perform the tests under stricter aseptic conditions. The temperature of samples should preferably be kept below 10 °C during transportation and storage.

Ensure that all personnel doing the testing are adequately trained and experienced in microbial techniques. The main methods for testing are:

19.6.1 Microscopic examination

This is used for examining fresh specimens and for fixed and stained ones. Algae and protozoa are normally examined in the fresh state in their original colour and shape and are easily visible. Bacteria are much smaller and retain their shapes on fixing.

19.6.2 Culture

A suitable growth medium is inoculated with the organisms of interest and the resulting culture studied. The medium may be solid (agar – a jelly derived from seaweed) or liquid.

The colonies on a solid medium will have a distinctive shape, colour and texture, while the culture in a liquid medium may produce certain gases or acids which are characteristic.

19.6.3 Counting

The most obvious technique is microscopic counting, the number of cells within a certain area is counted and the concentration in the sample estimated.

A more positive method is to filter a sample through a very fine membrane, placing it on a suitable culture media and counting the number of colonies of the appropriate type after incubation.

Note:
In both the above methods, the indicator species is E. coli as its presence indicates the possible presence of pathogens while the absence of E.coli indicates safe water.

19.7 Record keeping

Records are kept for the following reasons: York and maintenance planning, prediction or forecasting, analysis breakdowns, cost budgeting, your own protection and design of new plants and for comparing results with those of similar plants.

The following records should be kept: analytical results, staff, plant, weather, flow, stocks, accidents, repairs and maintenance, running costs, etc. All records should be filed and easily accessible.

Activity 19.1

1. Name three types of volumetric glassware in the laboratory.
2. Describe briefly how you would lubricate a dirty stopcock of a burette.
3. What is the maximum allowable E.coli count in potable water?
4. Name three general rules for cleaning volumetric glassware.
5. Name the indicators used in determining:
   a) Total hardness
   b) Calcium hardness
   c) Alkalinity

Self-Check

I am able to:	**Yes**	**No**
• Explain minimum control analysis:		
o analysis required		
o reasons for analysis		
• Describe elementary laboratory procedures and practice		
• Explain the use of standard solutions		
• Describe sampling procedures		
o frequency of sampling and analysis with interpretation of results		
o Brief introduction to bacteriological analysis		
• Describe and maintain record keeping		
If you have answered 'no' to any of the outcomes listed above, then speak to your facilitator for guidance and further development.		

Past Examination Papers

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APRIL 2012

NATIONAL CERTIFICATE

WATER TREATMENT PRACTICE N3

(8120033)

5 April (X-Paper)
09:00 – 12:00

This question paper consists of 6 pages.

TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer ALL the questions.
2. Read ALL the questions carefully.
3. Number the answers correctly according to the numbering system used in this question paper.
4. Write neatly and legibly.

QUESTION 1

Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (1.1 - 1.10) in the ANSWER BOOK.

1.1 Floccotan is used to remove Phenol from industrial effluent. (1)

1.2 Ferric chloride can be used to reduce phosphate levels in water. (1)

1.3 Fluoride could be induced into drinking water if concentrations are too low. (1)

1.4 Potassium permanganate is an oxidising agent. (1)

1.5 Electrical conductivity is an indication of the salt content in water. (1)

1.6 Hydrochloric acid is a strong acid. (1)

1.7 Activated carbon can be used to remove bad smells in drinking water. (1)

1.8 Bromium can be used as a disinfectant. (1)

1.9 The buffer capacity of potable water is always very low. (1)

1.10 Pre-chlorination is a prerequisite when treating water with high levels of humic organic substances. (1)

[10]

QUESTION 2

Complete the vacant spaces in the TABLE below by converting the quantities as indicated (use the numbers in brackets for your answer):

Liters	Cubic liters	Mega liters
100	(2.1)	(2.2)
(2.3)	1,5	(2.4)
(2.5)	(2.6)	0,25
(2.7)	999	(2,8)

[8]

QUESTION 3

Use the given atomic masses to calculate the molecular masses of the following compounds:

3.1 Ferric chloride (2)
3.2 Sulphuric acid (2)
3.3 Carbon dioxide (2)

3.4 Ferro sulphate (2)

Atomic masses are as follows:

Iron = 55,85
Chloride = 35,5
Sulphur = 32
Hydrogen = 1
Oxygen = 16
Carbon = 12

[8]

QUESTION 4

4.1 The total daily inflow to a water purification plant is 8 000 m^3. The suspended solid concentration after added flocculants is 50 mg/l and the suspended solid concentration of the settled sludge is 450 mg/l. (5)

Calculate the expected volume of sludge extracted daily.

4.2 A circular reservoir with the following measurements is used for mixing the flocculant:

Diameter: 20 meters
Depth: 7 meters

You have to prepare a 25 mg/l flocculant solution on a monthly base in this reservoir which is sufficient for a month’s use. The chemical cost is R80,00 per ton.

4.2.1 Calculate the capacity of the tank. (4)
4.2.2 How much chemicals, in tons, would you use annually? (4)
4.2.3 Calculate your cost per year for these chemicals. (4)

[17]

QUESTION 5

5.1 What are the indicators for the identification of pollution in water resources? (4)

5.2 Write the balanced chemical reactions for the following: (5)

Aluminium sulphate reacts with water.

[9]

QUESTION 6

Draw the following TABLE in your ANSWER BOOK, by using X. Indicate the properties of each chemical. Chemicals can have one or more properties.

CHEMICAL	COAGULANT OR AID	ALKALINITY AND Ph CONTROL	DISINFECTION	DECHLORINATION	CORROSION CONTROL	SOFTENING
CALCIUM HYDROXIDE						
CALCIUM OXIDE						
CARBON DIOXIDE						
SODIUM CHLORIDE						
OZONE						

[11]

QUESTION 7

7.1 Name the disadvantages of pressure filters when compared to gravity filters. (4)

7.2 Describe the procedure that should be followed to ensure effective functioning of a new sand filter. (4)

[8]

QUESTION 8

8.1 Discuss the role of pH on the effectiveness of free residual chlorine as a disinfectant. (4)

8.2 Name **FIVE** golden rules in the effective disinfection of drinking water when using chlorine gas. (5)

[9]

QUESTION 9

9.1 The oxidation of iron with potassium permanganate is more effective than the oxidation with chlorine. (6)

Motivate this statement with scientific facts.

9.2 Write the **TWO** reactions that ferrous-bicarbonate, as found in natural water, undergoes during aeration. (6)

[12]

QUESTION 10

Calculate the missing values.

Show your calculations.

Rate of flow L/s	Dosing rate Ml/min	Dosage mg/l as FeC_{13}
100 1/s	……… ml/min of a 43% m/m FeC_{13} solution	40

[8]

TOTAL: 100

Marking Guidelines

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APRIL 2012

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WATER TREATMENT PRACTICE N3

(8120033)

QUESTION 1

1.1 False (1)
1.2 True (1)
1.3 True (1)
1.4 True (1)
1.5 True (1)
1.6 True (1)
1.7 True (1)
1.8 True (1)
1.9 False (1)
1.10 True (1)

[10]

QUESTION 2

2.1 0,1 (1)
2.2 0,0001 (1)
2.3 1500 (1)
2.4 0,0015 (1)
2.5 250 000 (1)
2.6 250 (1)
2.7 999000 (1)
2.8 0,99 (1)

[8]

QUESTION 3

3.1 $Ferric\ chloride\ =\ 55.85+\ 3(35.6)=162.3$ (2)
3.2 $Sulphuric\ acid\ =\ 2(1)\ +\ 32\ +\ 4(16)\ =\ 98$ (2)
3.3 $Carbon\ dioxide\ =\ 12\ +\ 2(\ 16)\ =\ 44$ (2)
3.4 $Ferro\ sulphate\ =\ 55.85\ +\ (32\ +\ 4*\ 16)\ 2\ =\ 247.85$ (2)

[8]

QUESTION 4

4.1 $VICI\ =\ V2C2$ (5)
$(8000M3)\times(50\ mg/1)\ =\ V2\ \times\ 450\ MG/L$
$V2\ =\ 8000\times 50/450$
$888{,}88\ M3$

4.2

4.2.1 $V\ =\ \#\ \times\ r.\ \times\ r\ \times h$ (4)
$V\ = 3.142\ \times\ 10\ \times\ 10\ \times 7$
$V\ = 3.142\ \times\ 700$
$V\ =\ 2199,4\ m3$

4.2.2 $25\,mg/1\ =\ 25\ g/m3$ (4)

$Reservoir\ is\ 2199{,}4\ m3$

$25\ \times\ 21999{,}4\ =\ 54\,985\ grams\ flocculant$

$For\ 12\ months\ use =\ 12\ \times 54\,985$

$=\ 659\,820\ gram\ per\ annum =\ 659,820\ kilograms$

$=\ 0{,}659820\ tons\ per\ annum$

4.2.3 $80 \times\ 0{,}6598\ =\ R52{,}7856$ (4)

[17]

QUESTION 5

5.1 (4)

- A sudden increase or decrease in Ph
- Excessive algae growth
- Increased colour
- Increase in total dissolved salts or increase in e.c
- A decrease in the oxygen saturation point

5.2 (5)

$$A\,12(S04)3.14H20\ +\ H20\ -------\ 2A\,13+\ +3S04--\ +\ 15H20$$

$$S04--\ +\ HO -----------------\ H2S04$$

[9]

QUESTION 6

Chemical	Coagulant or aid	Alkalinity and Ph control	Disinfection	Dechlorination	Corrrosion control	Softening
Calcium Hydroxide		X			X	X
Calcium oxide		X			X	X
Carbon dioxide		X				X
Sodium chloride			X	X		
Ozone		X				

[11]

QUESTION 7

7.1 Because the water is fed to the filters under pressure it is difficult to add any chemicals which may be needed. Also difficult to get proper mixing. (4)

Pressure filters are completely closed and water and sand are therefore not visible. The efficiency of the back washing can therefore not be observed. The shape of the pressure filter makes it impossible to obtain an effective design.

Inspection of any part of the pressure filter is very difficult. Because these units work under pressure there is always the temptation to pass excessive amounts of water through.

7.2 Backwash the filter in a normal way. Before turning off the backwash water, slowly close the valve for at least 5 minutes. (4)

Drain the filter.

Examine the sand in the filter. Remove the fine sand from the filter. Repeat the process. Repeat the process every time the filter is washed until all the fine sand is removed. The same process should be executed whenever more sand is added.

[8]

QUESTION 8

8.1 Chlorine gas can only exist in water in its free form if the water's pH is less than 5.0. When chlorine is added to the water with a pH between 5 and 6 hypochlorous acid and hydrochloric acid are formed: (4)

$$======== C12 + H20 ----- HOCI + HCI$$

In most natural waters the hydrochloric acid is neutralised by the alkalinity of the water and the hypochlorous acid ionises to form hydrogen ions and hypochlorite ions:

$$HOCI = H+ + OCI$$

The equilibrium of this reversible reaction is influenced by the Ph of 6; both hypochlorus acid and hypochlorite ions are present. The hypochlorite ion concentration increases while the hypochlorous acid concentration decreases with increasing Ph until at a Ph 10 and higher only the hypochlorite ion remains.

This means that water with a high Ph requires more chlorine to compensate for the lower disinfecting ability of the hypochlorite ion.

8.2 (5)
- The chlorine dose required must be predetermined
- Must be uniformly dosed
- Must be continuous

- Good control
- Bacteriological tests to be done regularly

[9]

QUESTION 9

9.1 The reaction takes place rapidly to form a brown or black deposit. If hydrogen sulphate is present in the water a contact period of between 5 - 20 minutes should be allowed. It is important to realize that once a chemical reaction takes place rapidly and also when such a reaction forms a precipitation, the chances of that deposit to be dissolved are remote. In the case with chlorine a further reaction after chlorination is necessary to form a precipitate. **(6)**

9.2 $Fe(HC03)2 + H20 ----- FeO.H20 + 2C02 + H20$ **(6)**

$4Fe0.H20 + 02 ------------- 2Fe203.3H20$

[12]

QUESTION 10

$Q = 1001/s$
$B = X$
$A = 43\% \times 10 mg/l$
$C = 40\, mg/1$
$B = C \times Q / A - C$
$= 40\, mg/I \times 100\ 1/s$
$= 4000\, I/s\ /\ 4299960$
$,93\, I/s$
$,93\, mI/s$
$55.81\, mImin$

[8]

TOTAL: 100

Past Examination Papers

higher education
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Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

AUGUST 2011

NATIONAL CERTIFICATE

WATER TREATMENT PRACTICE N3

(8120033)

29 June (X-Paper)
09:00 – 12:00

Calculators may be used.

This question paper consists of 7 pages.

TIME: 3 HOURS
MARKS: 100

INSTRUCTIONS AND INFORMATION

1. Answer ALL the questions.
2. Read ALL the questions carefully.
3. Number the answers correctly according to the numbering system used in this question paper.
4. Write neatly and legibly.

QUESTION 1

Various options are given as possible answers to the following questions. Write only the letter (A - D) next to the question number (1.1 - 1.15) in the ANSWER BOOK.

1.1 Silver is a/an ... (1)

A cation.
B molecule.
C anion.
D radical.

1.2 A water molecule consists of one oxygen atom as well as ... (1)

A two water molecules.
B one water molecule.
C one hydrogen molecule.
D two hydrogen atoms.

1.3 The symbol for calcium is ... (1)

A Ka
B C
C ca
D Ca

1.4 Water is turbid when it ... (1)

A contains a lot of dissolved solids.
B has settled.
C contains sand.
D contains visible materials in suspension.

1.5 Iron and manganese ... (1)

A are not harmful to the health of human beings.
B are attractive in water.
C cannot be precipitated.
D are used in medicine.

1.6 Phenol compounds are present in ... (1)

A water.
B paper mill effluent.
C sugar mill effluent.
D effluent from Iscor.

1.7 The following aspect plays a major role in preventing mud balls: (1)

A Manganese
B Chlorine
C Flocculant
D Air blown for sufficient time

1.8 Which **ONE** of the following is a gas? (1)

A Magnesium
B Sodium
C Water
D Hydrogen

1.9 Post chlorination means ... (1)

A over chlorination.
B break point chlorination.
C chlorination of final effluent.
D chlorination of raw water.

1.10 The following metal is easy to remove from water: (1)

A Sodium
B Potassium
C Iron
D Magnesium

1.11 Corrosion always occurs at the ... (1)

A cathode.
B anion.
C anode.
D cation.

1.12 If the Langelier-index is positive, the water is ... (1)

A in chemical balance.
B scale forming.
C corrosive.
D useless.

1.13 Floccotan is ... (1)

A ideal for rust prevention.
B ideal to use with terri-chloride.
C ideal to use with pre-chlorination.
D organic in nature.

1.14 The following is a physical change of matter: (1)

A Rusting of iron
B Melting of ice
C Air pollution
D Acid in water

1.15 The adsorption properties of the filter media and the floc are influenced by the ... (1)

A temperature.
B Van der Waal's forces and electrochemical properties.
C sedimentation.
D chemicals used.

[15]

QUESTION 2

Indicate whether the following statements are TRUE or FALSE. Write only 'true' or 'false' next to the question number (2.1 - 2.15) in the ANSWER BOOK.

2.1 South Africa is a water rich country. (1)

2.2 Water for domestic use should have a maximum free chlorine concentration of 1 mg/ℓ. (1)

2.3 Alum is an organic flocculant. (1)

2.4 The specific gravity for water is 1. (1)

2.5 Mercury is a liquid. (1)

2.6 Floccotan is used to remove phenol from industrial effluent. (1)

2.7 Ferric chloride can be used to reduce phosphate levels in water. (1)

2.8 Fluoride could be induced into drinking water if concentrations are too low. (1)

2.9 Potassium permanganate is an oxidising agent. (1)

2.10 Electrical conductivity is an indication of salt content in water. (1)

2.11 Hydrochloric acid is a strong acid. (1)

2.12 Activated carbon can be used to remove bad smells in drinking water. (1)

2.13 Bromium can be used as a disinfectant. (1)

2.14 The buffer capacity of potable water is always very low. (1)

2.15 Prechlorination is a prerequisite when treating water with high levels of humic organic substances. (1)

[15]

QUESTION 3

3.1 Differentiate between the presence of magnesium sulphate and sodium chloride in drinking water with reference on the medical consequences if these compounds exist in high concentrations. (8)

3.2 Name the **FOUR** main groups into which surface waters could be classified. (4)

3.3 Write short notes on the purpose of dosing of calcium carbonate in highly coloured water with little suspended matter. (6)

3.4 What are the observations that could lead to the identification of pollution in surface water? (5)

[23]

QUESTION 4

4.1 Name the **THREE** principles of flocculation. (3)

4.2 Distinguish between *floc formation* and *conditioning*. (10)

4.3 Briefly discuss and explain the chemical composition of water with a pH of 7. (7)

4.4 Show the chemical reaction between aluminium sulphate and a large amount of alkalinity. (5)

[25]

QUESTION 5

5.1 Calculate the effective concentration of a flocculant dosed in raw water. The following information is given: (6)

Raw water flow = 0,5 m^3/s
Flocculant dosed = 1,0 kg/minute.

5.2 Determine the capacity of a reservoir with the following dimensions: (6)

Diameter = 50 meter
Height = 10 meter

5.3 How long will it take to fill up the reservoir in QUESTION 5.2 if a pump with capacity of 10 l/s is used? (6)

[18]

QUESTION 6

6.1 Name the **FOUR** definite regions in a break-point chlorination curve. (4)

[4]

TOTAL: 100

Marking Guidelines

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WATER TREATMENT PRACTICE N3

(8120033)

QUESTION 1

1.1	A	(1)
1.2	D	(1)
1.3	D	(1)
1.4	D	(1)
1.5	A	(1)
1.6	D	(1)
1.7	D	(1)
1.8	D	(1)
1.9	C	(1)
1.10	C	(1)
1.11	C	(1)
1.12	B	(1)
1.13	D	(1)
1.14	B	(1)
1.15	B	(1)

[15]

QUESTION 2

2.1	True	(1)
2.2	False	(1)
2.3	False	(1)
2.4	True	(1)
2.5	False	(1)
2.6	False	(1)
2.7	True	(1)
2.8	True	(1)
2.9	True	(1)
2.10	True	(1)
2.11	True	(1)
2.12	True	(1)
2.13	True	(1)
2.14	False	(1)
2.15	True	(1)

[15]

QUESTION 3

3.1 The magnesium and the sulphate content should be considered together because it forms epsom salts. Increasing concentrations make the water bitter and causes diarrhoea in man and animals.

Sodium chloride is table salt. Increasing concentrations also effects the taste of the water. People receiving medical attention for sugar diabetes, high blood pressure, etc. should restrict their salt intake. Water with a high salt content is normally corrosive.

3.2

- water with a high suspended solids content but with a low color intensity
- water with a low suspended solids content but with a high color intensity
- water with a low turbidity, low colour, and low in dissolved minerals
- resources whose physical, chemical and bacteriological properties deteriorate
- annually due to pollution.

3.3 because highly colored water contains very little suspended matters, besides its very low mineral content, the floc which forms after the addition of aluminum sulphate is usually very light and does not settle very readily.

Adding powder calsium carbonate serves a dual purpose , it acts as a nucleus about which the floc can form more readily to produce a heavier floc and it also reacts slowly with the dissolved carbon dioxide to increase the stability of the water.

3.4

- a sudden increase or decrease in Ph
- excessive algae growth
- increased color
- increase in tds or an increase in e.c
- decrease in the oxygen saturation point

[23]

QUESTION 4

4.1

- addition of the flocculant
- initial formation of floccules
- conditioning (flocculation)

4.2 When the floc formation is distributed in the water certain physical and chemical reactions occur. The basic reaction which occurs is the neutralization of the negative charges on the colloids by the positive charges on the flocculant. Floccules result but are still too small to settle out quickly on their own.

Conditions must be created to enable these floccules to collide and so form larger, heavier floc particles which will quickly settle. The water should be slowly aggitated to enable the particles to collide, but the aggitation should not be so gentle that the particles are permitted to settle at this stage.

4.3 The chemical formula for water is H20 or HOH.
A small portion of the water is ionised to form H+~ the hydrogen ion, and OH' the hydroxyl ion. Water could then be represented as $HOH --- H+ + OH-$.

Hydrogen ions indicate an acid solution while hydroxide ions indicate an alkaline solution. Because equal numbers of both are present in pure water, the water will be neutral with a Ph of 7,0. A Ph of less than 7 indicates the acid range while a pH of greater than 7 indicates an alkaline range.

4.4 Al2(S04)3 + 3Ca(HC03)2 ---------2Al(OH)3 + 3CaS04 + 6C02

[25]

QUESTION 5

5.1 $raw\ water\ flow = 0{,}5m3/s$

$flocculant\ dosed = 1{,}8\ kg/min$

$effective\ concentration\ of\ flocculant\ dosed = x$

$0{,}5m3/s = 0{,}5 \times 60 = 30m3/min$

$30m3 = {,}03MI/min$

$dosing = 1{,}8kg/min/\ 0{,}03 = 60kgll = 60mg/l$

5.2 $capacity\ of\ a\ reservoir = x$

$diameter = 50\ meter$

$height = 10\ meter$

$volume = \# \times r \times r \times h$

$3.14 \times 25 \times 25 \times 10$

$= 19\ 643\ m3$

5.3 $how\ long\ at\ pump\ rate\ of = 10\ I/s$

$1\frac{0I}{s} = 1\ 0 * 60 \ * = 600I/min$

$0{,}6\ m3/min$

$19\ 643/0{,}6 = 32\ 738min$

$545\ hours.$

[18]

QUESTION 6

- Region where chlorine is broken down by reducing substances
- Region where chlorine organic compounds and chloramines are formed
- Region where. chloramines and chlorine organic compounds are broken down
- Last region where free residual chlorine and a limited amount of organic chlorine compounds are found.

[4]

TOTAL: 100

N3 Water Treatment Practice is one of many publications introducing the gateways to Engineering Studies. This course is designed to develop the skills for learners that are studying toward an artisanship in the water and waste water treatment and related technology fields and to assist them to achieve their full potential in an engineering career.

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