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Basics of Water Purification Process

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ABSTRACT: Various types of impurities are contained in water that is available from various sources weather ground surface water. But the raw water available from various sources cannot be used until it is treated for safety of use for any purpose. Therefore, the objective of treatment or purification of water is to eliminate all impurities that make water unsafe for use. The elimination of impurities may not be complete total but is reduced to an extent of sustainability for the intended purpose. The nature of treatment to be given to raw water hence depends upon the initial quality of raw water and the degree of desire of purity to be attained after treatment.
It is not possibly essential that all treatment units processes will have to be employed but what type of treatment will depend on the quality of water and its source. The treatment of water processes involved may include screening, aeration, plain sedimentation, sedimentation with coagulation, filtration, disinfection, softening.

KEYWORDS: impurities, raw water, treated for safety, unsafe, quality of raw water, plain sedimentation, coagulants, filtration, disinfection, flocculation.

I. INTRODUCTION

Before water is supplied to the end users, it requires complete treatment for it to be free from any form of impurities. Admittedly, certain dissolved salts such as iron, calcium, magnesium and fluorine are good for health and assist in food digestion and assimilation and make water tasteful and because of this, absolute purification of water is not advised. Therefore, purification of water means removal of impurities that are not good for health (such as arsenic, barium, cadmium, chromium, cyanide, lead and copper) through treatment. This means that un-harmful and useful impurities are not to be removed during treatment of water for purity.

The most reason for treatment of water is to produce a wholesome water. Any water that does not contain all or any of the harmful impurities (arsenic, barium, cadmium, chromium, lead and copper) and that does contain other salts.

TREATMENT PROCESS

It is not possibly essential all treatment units processes will have to be employed but what type of treatment will depend on the quality of water and its source. For example, raw water from rivers, aeration is not required and that from lake, screening and sedimentation is not needed because suspended and floating impurities all may have settled in the basin of the lakes but aeration is a must since lake waters generally have objectionable odour. Only disinfection treatment may be done in the case of raw water from deep wells.

Hence the character and degree of treatment directly depends upon the nature and source of the raw water. The list of treatment processes involved in the treatment of water are:

i. **Screening**: This process excludes floating matter and it takes place at the intake unit.
ii. **Aeration**: This is the process that removed elements that will be causing taste and odour.
iii. **Plainsedimentation**: Suspended impurities such as silt, sand, clay, leave etc are eliminated in this process.
iv. **Sedimentation with coagulants:** This is the process where fine suspended particles and possible bacteria are removed.
v. **Filtration:** For every fine particles and colloidal matter that may have escaped from sedimentation process, this process is where they are eliminated. Micro-organisms are also eliminated very largely here.
vi. **Disinfection**: This is the process that renders water from unsafe condition against disease producing bacteria.
vii. **Other process which are used in specific case only are:**

a. Hardness that is beyond permissible limits is eliminated.
b. Where colour, taste and odour are issues, they are removed
c. Removal of iron and manganese in the case that their presence are detected.
d. Fluorine are maintained to remain between 1 to 15 ppm by adding in the case of deficiency and removing in the case of excess. Water

purification/treatment flow diagram is as shown in figure 2.

TREATMENT PLANT LAYOUT

A complete water treatment plant layout consists of the following;

i. Intake works including the pumping station plant
ii. Plain sedimentation
iii. Sedimentation with coagulation
iv. Filtration
v. Disinfection
vi. Portable water storage reservoir
vii. Pumping plant for pumping purified water from clear waste storage reservoir to an elevated service reservoir.
viii. In cases where water is hard, softening plant has to be used before filtration plant.
ix. Distribution system.

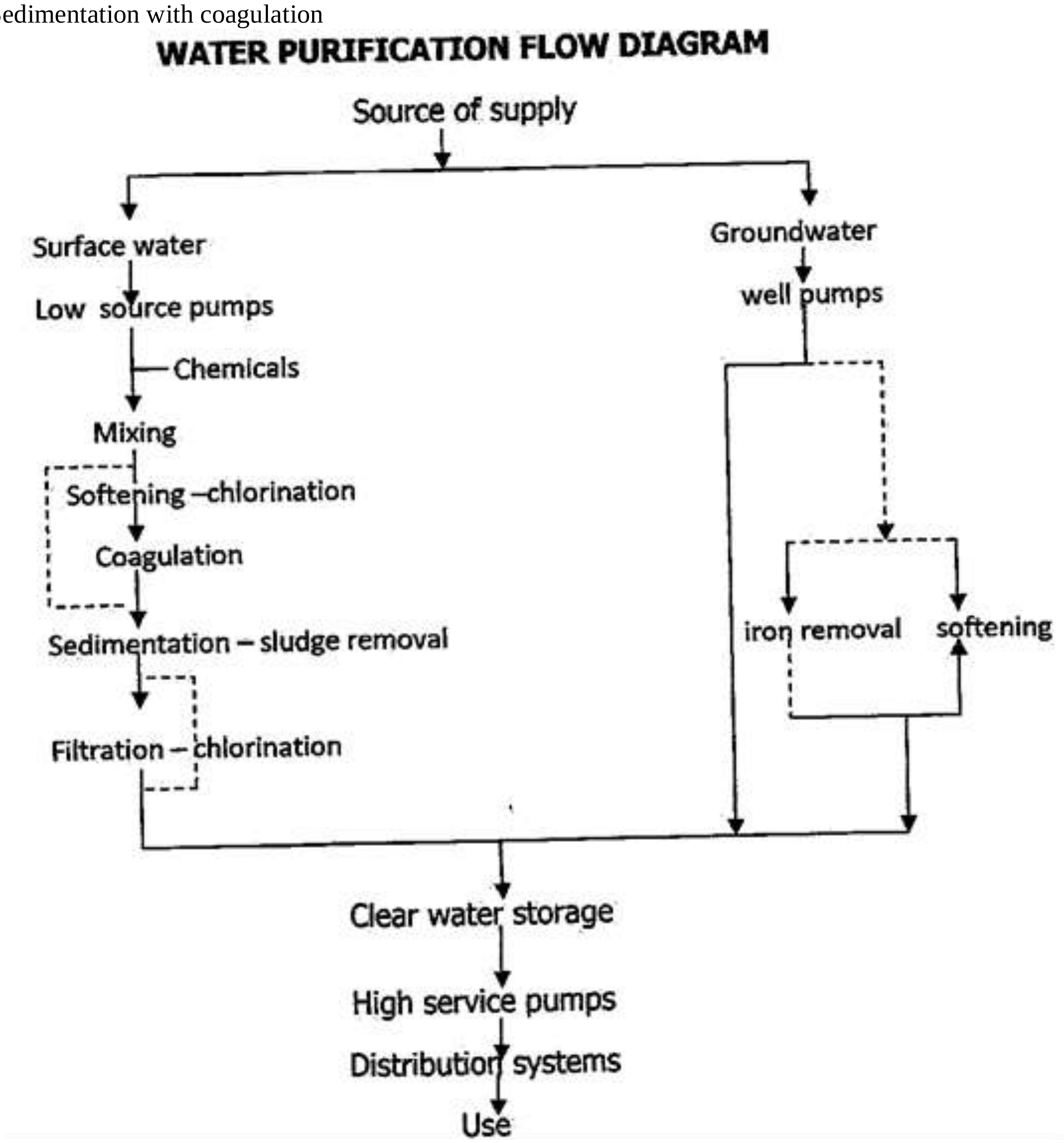

Figure 1: Flow diagram of water purification

Sedimentation

Sedimentation process is of two types. These are plain sedimentation and sedimentation with coagulation. For water that contains large amount of suspended impurities of reasonably large size, preliminary sedimentation could be economical to remove them.

Plain Sedimentation

The plain sedimentation process is when raw water is allowed to be retained in an inactive state of quiescent (dormant or inert) in large tanks for a given time, and during this retention period that the raw water is in a still state, bigger coarser size of suspended impurities settles down at the bottom of the large tank but modern approach is

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that instead of holding water quiescent in the tank, it is kept flowing with very small velocity of flow. Plain sedimentation is recommended in the case of the presence of large amount of settleable suspended matter. Raw water from lakes and impounded reservoirs do not required sedimentation but river water requires sedimentation. Sedimentation tanks are also refers to as settling tanks. The advantages of plain sedimentation includes the following;

i. In subsequent processes that will follow, the load burden of impurities are reduced and can be more effectively controlled.
ii. There will be no lost of chemical with sludge discharge from the plain settling basins and hence the cost of cleaning the chemical coagulating basins is reduced and fewer chemical in subsequent treatment will therefore be needed.

Principle of sedimentation of discrete particles and the theory of sedimentation

a. The principle of sedimentation

Some of the suspended impurities that are present in raw water have specific gravity greater than that of water, so when the water is still, these impurities settles down under gravity and in the case of normal raw water supplies, these particles remain in suspension due to the turbulence that follows the supplies in water storage to the water, these impurities tend to settle down at the bottom of the tank that provided the storage – this is the principle behind sedimentation.

The bottom of the tank or the basin where the flow of the water is retarded is known as the settling tank or sedimentation tank or sedimentation basin or **clarifier**. The average time in which the water is retained or detained in the tank is called **detention period**. In the settling principles, settleable suspended particles are regarded discrete particles. Particles that do not change their shape, size and weight as they settles or rises, are called **discrete particles.**

b. The theory of sedimentation:

Velocity of settling down of the particles in the case of still water increases till when the frictional resistance of the water approaches the impelling forces (compelling force) until the vertical velocity of settlement remains constant. The velocity of settlement is called **settling velocity**. The following factors opposes the settlement of a particle in water brought to rest.

i. The velocity of flow which carries the particles horizontally (in this consideration, the greater the area of flow, lesser the velocity and hence more easily the particle will settle down).
ii. The viscosity of water that the particle is travelling (here the viscosity varies inversely with temperature).
iii. The size, shape and specific gravity of the particle. Greater the specific gravity is, more very readily the particle will settle and the setting rate is as well affected with the size and shape of the particle.

Considering the above factors in the theory of sedimentation, the weight (wt) and volume (vol) of a spherically shaped particle varies with the cube of the diameter.

Noting that;

Vol = $\frac{\pi d^3}{6}$, d = diameter or its size and its area as well varies with the square of the diameter

Noting that A = $\frac{\pi d^2}{4}$

This is why very small sized particles will settle very slowly.

Therefore,

It follows clearly that the size and shape of the particles do affect their setting velocities abilities. The stoke's law expresses the flow, the viscosity of water, and the size or shape, specific gravity of the stoke equation is given and expressed as

$$Vs = \frac{g}{18}(\rho_\tau - 1)\frac{d^2}{,} \quad \text{for } d < 0.1\text{mm} \text{ ------------------ (1)}$$

Equation 1 above is valid for viscous flow and small sized particles represented by $R\tau < 0.5$

Where

V_s= Velocity

g = force of gravity

ρ_τ = mass density of the particle

d= diameter

μ = dynamic viscosity

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Still on the stoke law, as a solid particle settles down in water, its downward settlement is opposed by the drag force (fd) offered by the water. The effective weight of the particle (actual wt buoyancy) will cause the particle to accelerate in the beginning till it will attain sufficient velocity (Vs) at which the drag force becomes equal to the effective weight of the particle. And after attaining this velocity, the particle will fall down with the constant velocity (Vs) and then drag force offered by the fluid is then given in Newton's law as:

$$Fd = CdA\frac{Pr^2}{2} \Longrightarrow C_D A.\rho_w.\frac{V^2}{2} \quad \text{---------------------------(2)}$$

Where
Fd= drag force
Cd = coefficient of drag which depend upon the inertia of the particles and the velocity of water
A = Area of particle that is projected
P= weight of unit volume of the particle
P_w= mass density or weight of a unit volume of water (fluid)
V = velocity of fall which is the relative velocity between the particles and the fluid or settling velocity of a spherical particle.
r= radius of particle

Impelling force:
$F_1 = (P_1 - P)gV_1$ --------------------------------- (3)
For
F_1 = impelling force
P_1 = weight of a unit volume of particle of fluid or mass density of particle
P = weight of a unit volume of fluid or mass density
g = acceleration due to gravity
V_1 = volume of the particle = $\frac{\pi d^3}{6}$
Where d = diameter of particle.
The velocity of settlement "v" increases until "fd" is equal to "F_1".
So by putting $\frac{\pi d^2}{A}$in place of A since and because projected area of the sphere is $\frac{\pi d^2}{4}$ and equating (2), then

$V = \sqrt{\frac{4g\,(P-P)d}{3\,X\,Cd\,X\,P}}$ ------------------ (4)

Or $V = \sqrt{\frac{4g}{3Cd}}(P_1 - 1)d$
Where P_1 = specific gravity of the particle
P = specific gravity of water = 1
But the Renold's number which relates inertia to viscous force is required to be introduced to equation (4). The Renold's number is:

$R = \frac{Vdp}{\mu}$ ---------------------(5)

Where
R = reynold's number
V = settling velocity
d = particle diameter
P = mass density of the fluid in gm/cc or mass density of fluid
μ = absolute viscosity of the fluid in center pole (i.e gm/cm sec).
Knowing that the stoke's law for drag for small settling spheres in viscous fluid while neglecting inertia force is:
$Fd = 3\pi\mu vd$ ------------------- (6)
Now equating (2) and (6)
$C_A = \frac{24 \times \mu}{vdp} = \frac{24}{R}$
Therefore $\frac{\mu}{Vdp} = 1/R$

If we now place value of Cd in equation (4)
Then $V = \frac{1}{18}\frac{g}{\mu}(P_1 - P)d^2$ ------------------- (7)
$= \frac{1}{18}\frac{g}{\mu}(P_1 - 1)d^2$ -------- -----------(8)
$Vs = V = \frac{g}{18}(P - 1)\frac{d^2}{\mu}$ -------- --------- (1)
Where: Vs = v and v = μ
If we now reconcile equation 1 and 8
Then,
Vs = velocity of settlement of particle which is assumed to be spherical in mm/sec
g = 9810 mm/sec^2
p_1 = mass density of particle settling in gm/sec
p = S.G water = 1, d = diameter of settling particle in mm
μ = viscosity of water in centi-stokes

If we were asked to find the settling velocity of a discrete particle in water under the following conditions when Renold's number is less than 0.5. The diameter and specific gravity of the particles is 5x10^{-3}cm and 2.65 respectively, water temperature is 20^{0}C. Note that kinematic viscosity (μ) of water at 20^{0}C = 1.01x10^{-3}cm^2/sec.

Then from Stoke'sequation;
$Vs = (G - 1)\frac{d^2}{v}$ where G = P_1 and V = μ_1,
But Vs = v for d< 0.1 and R < 0.5 as given.

Then considering cgs units (where **c** is centimeter for distance, **g** is the gram for mass and **s** the second for time name after George Gabriel Stoke).

Then $Vs = \frac{g}{18}(G-1)\frac{d^2}{v}$

Implying that $V = \frac{g}{18}(P_1 - 1)\frac{d^2}{\mu}$

Where
G = 2.65
d $=5x10^{-3}$cm = 0.005mm< 0.1 (ok)
v = $1.01x10^{-2}cm^2/sec$
g = $981cm^2/sec$

$\therefore \quad Vs = \frac{981}{18} \text{ x } (2.65-1)\frac{(5 \text{ x } 10^{-3})^2}{1.01 \text{ x } 10^{-2}}$ cm/sec

$= \frac{981}{18} \text{ x } \frac{1.65 \text{ x}25 \text{ x } 10^{-6}}{1.01 \text{ x } 10^{-2}}$ cm/sec = 0.22 cm/sec

Factors that Influence Sedimentation

The factors that influence sedimentation are as enumerated below:

i. Size, shape and weight of the settling particles
ii. Temperature and viscosity of water
iii. Surface overflow
iv. Surface area
v. Velocity of flow
vi. Inlet and outlet arrangement
vii. Detention period
viii. Effective dept of the setting tank

Classification of Sedimentation Tank

Sedimentation tanks are classified into two categories and which are:

i. Classification in terms of the flow
ii. Classification in terms of the shape

i. Classification according to flow:

In this category, tanks are either

a. Draw and fill type or
b. Continuous type

a. **Draw and fill:** Here water is filled and allowed to rest for a while in which period, the heavy suspended particles settles down at the bottom of the tank. The tank is then clean off of silt after the clear water is drawn off, and then again filled up with water. The cycle is then continued. The detection period or the rest period is normally 24 hours. This type of sedimentation tank has the disadvantages of not having a continuous flow (flow of supply), since a number of units are required, it involves a large number of land area and lastly, the rest period is too long for 24 hours.

b. **Continuous flow type tanks:** In all the elements that opposes or hinder the settling of the particles under gravity, it is only velocity of flow that is controlled in plain sedimentation. So by reducing the velocity of flow, a reasonable large amount of suspended impurities can be eliminated from water. In this tanks water continuously keeps on flowing but with a very small uniform velocity. In continuous flow tanks, water enter the tank via the inlet, at an end of its one side, and then travels slowly towards an outlet located on opposite side end. In order to prolong the travel path of the flow, provision of baffle walls are made in the tank. The velocity of flow should be adjusted in the design and construction stages so that time taken for a particle of water to travel from one end to the other should be slightly more than needed for the suspend setting particles in water to settle down.

The inlets and outlets design should be such that they cause a minimum disturbance to the flowing water in the tank. The design should also meet the following requirements:

a. The amount of water flowing out from the tank in 24 hours should be at least equal to the daily demand.
b. Velocity of flow should be well adjusted so that suspended impurities of coarser nature are removed.
c. Sludge is the settlement taking place at the bottom of the tank, and its deposition should be maximum close and near the inlet and least near the outlet.

ii. **Classification of sedimentation tanks based on shape:** The shape of the tanks in this classification maybe:

a) Rectangle
b) Circular
c) Hopper bottom

a) **Rectangular sedimentation tanks:** As the name of the shape applies, they are rectangular in shape and plan containing a number of baffle walls. Baffle walls prolongs the path of travel for the flowing water to attain a longer and more detention period in comparatively smaller setting tank and prevent short circuiting as well. They are provided with channels inlet and outlet extending to the full length of the tank. A number of units of rectangular tanks having a common inlet pipe and outlet can be provided when quantity of water to be handled is quite large and it is not possible to cater such an amount by one unit only. Floor between baffle walls are made sloping in such a way that

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sludge keeps on accumulating at the point which is located at mid-width of the tank. The sludge is drain off from time to time through sludge valves under hydrostatic pressure.

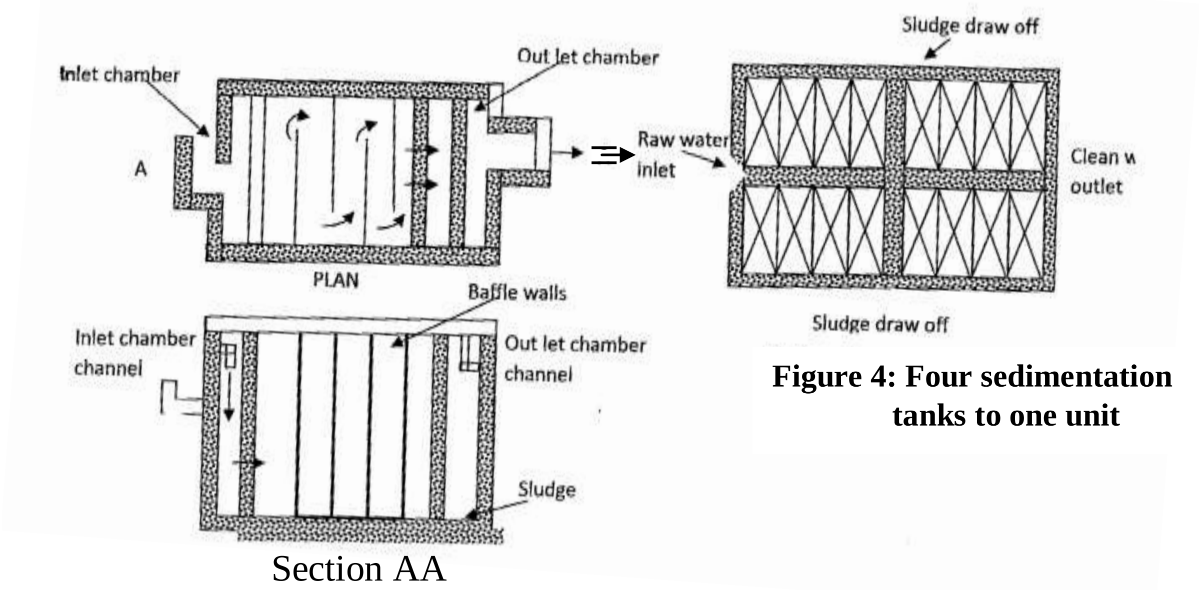

Figure 4: Four sedimentation tanks to one unit

Figure 2: Rectangular settling basin tanks

b) **Circular tanks:** In plain sedimentation, circular tanks are usually not used rather, they are used in sedimentation with coagulation. They are either radial flow or circumferential flow types. During radial flow in tanks, all the settleable particles settle down on the sloping floor and sludge is removed by raking arm which continuously keeps on moving around the floor with a very small velocity. The maximum velocity of movement of raking arms should not exceed 4 to 5 metre per hour.

c) **Hopper bottom tanks (velocity flow tanks):** Hopper bottom tanks could be circular, rectangular or square in plan or shape but with their bottoms in the shape of hopper. Flow of water in these tanks take place in the vertical direction. The suspended particles that have a specific gravity more than one do not reverse in the direction and settle at the bottom, from where it is removed through sludge outlet under hydrostatic pressure. These tanks are generally used in sedimentation with coagulation.

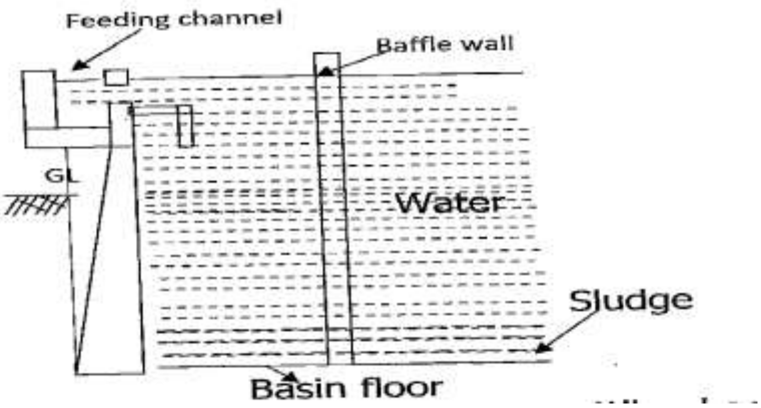

Figure 3: A typical bottom settling basin

Coagulation and coagulant aids

The hydraulic settling values of small size particles in water are very small making them to have requirement for longer time to settle in plain sedimentation tanks for instance, a silt particles of size about 0.04 to 0.06mm could require about 11 hours to settle down through a depth of 3m and clay particle of size 0.002mm will then require about 4 days time to settle the same height of 3m at normal temperature of around 25^0C. More to this, water may be containing colloidal impurities which are even finer than 0.0001mm and which also carry electrical charge on them. So due to the electrical charge, they remain continuously in motion and never settle down by gravity in water. Hence when water is turbid due to the presence of such fine size and colloidal impurities, plain sedimentation is of no use. It is also not possible to provide detention periods longer than 4-8 hours. The coagulation, becomes necessary when the turbidity is more than 30 – 50 ppm.

Coagulation is therefore a process where in dealing with water with such impurities, a chemical process has to be involved which removes all these impurities within reasonable period of 2 – 3 hours. This chemical process is called **coagulation**.

The object and purpose is to unite several colloidal particle of floc formulation and electrical charge.

i. Floc formulation

A thick insoluble gelatinous precipitate is produced when coagulant is added to the water and thoroughly mixed this insoluble gelatinous precipitate is refereed to and called FLOC. The floc has the ability and property of arresting the suspended impurities in water during the floc downward settlement toward the bottom of the tank. The floc so form (which is also the gelatinous precipitate) has the property and capability of removing fine and colloidal particles very quickly. The coagulation process so described and that has taken place also remove colour and undesirable taste.

ii. Electrical charge

Here all the colloidal particle have negative charge while the floc ions are found to possess the positive electric charge, hence the floc ions attract the colloidal particles and causes their removal by the settlement as a result at the bottom of the tank.

Coagulants

Coagulant elements can either be used alone or in combination. Some of the elements used as coagulant are:

a. Aluminum sulphate
b. Sodium aluminate
c. Copper sulphate + hydrate lime
d. Sodium aluminate + aluminate sulphate
e. Ferric chloride
f. Aluminum chloride
g. Sodium aluminate + ferric chloride
h. Ferric sulphate
i. Ferrous sulphate
j. Magnesium carbonate
k. Copper sulphate
l. Polyelectrolyte
m. Ferrous sulphate + hydrated lime
n. Ferric sulphate + hydrated lime
o. Ferrous sulphate + chlorine
p. Souddiumalumintae + magnesium chloride
q. Sodium aluminate + magnesium chloride
r. Aluminum sulphate + hydrated lime or caustic soda or sodium carbonate
s. Potassium permanganate + ferrous sulphate

All the mentioned coagulants have their own peculiar specific use purpose. Most commonly used coagulants in water treatment plans are:

i. Aluminum sulphate
ii. Sodium aluminate
iii. Chlorinated copperas
iv. Ferrous sulphate and line
v. Magnesium carbonate and
vi. Poly electrolytes.

Characteristic and reactions of them are discussed below:

a. Aluminum sulphate

Aluminum sulphate is commonly and simply known as alum. It is also called filter alum. Alum's chemical composition is $Al_2(SO_4).18H_2O$. Alum is the most commonly used chemical coagulant in water purification process works. Alum can only react with water in the presence of alkalinity. Floc is also known as aluminum hydroxide. When alum react alkaline water, it also forms carbon dioxide and calcium sulphate. Aluminum is most effective between pH range of 6.5 to 8.5. The dose varies from 5 to 30 milligrams per litrebut for normal water usual dose is 14 milligrams per liter and again it depend on various factors such as turbidity, colour, taste, pH value, temperature and other physical and chemical or bacteriological factors present in the raw water. Alum is the most commonly in use because it is very cheap, it reduces turbidity, it also reduce taste and colour to acceptable desire, it produce clear water, flocs formed by it are more stable and

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heavy, it is not harmful to health and finally, it is simple in working and does not required skill supervision.

Its chemical reactions are:

i. $Al_2(SO_4).18H_2O + 3NaCO_3 \rightarrow 2Al(OH)_3 + 3Na_2SO_4 + 18H_2O + 3CO_2$

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

iii. $Al_2(SO_4)_3.18H_2O + 3Ca(OH)_2 \rightarrow 2Al(OH)_3 + 2Ca_4SO_4 + 18H_2O$

b. Chlorinated copperas:

Chlorinated copperas is the resultant name of the combination of ferric sulphate$F_2(SO_4)_3$ and ferric chloride ($FeCl_3$). Ferric sulphate and ferric chlorides are produced when solution of ferrous sulphate is mixed with chlorine. About 1kg of chlorine reacts with 7.3kg of ferrous sulphate.

$6FeSO_4.7H_2O + 3Cl_2 \rightarrow 2Fe(SO_4)_2 + FeCl_3 + 42H_2O$

$F_2(SO_4)_3$ and $FeCl_3$ are both an effective floc and so also their combination. They can be independently use with lime to act as coagulant. The chemical reactions are:

$Fe_2(SO_4)_3 + 3Ca(OH)_2 \rightarrow 3CaSO_4 + 2Fe(OH)_3$
$2FeCl_2 + 3Ca(OH)_2 \rightarrow 3CaCl_2 + Fe(OH)_2$

It is the $Fe(OH)_2$ (ferric hydroxide) that forms the flocs. While ferric chloride is effective in pH range of 3.5 to 6.5 or above 8.5, ferric sulphate is effective in pH range of 4 to 7 and above 9. It is a very valuable and effective coagulant for eliminating colour more particularly when the pH value of water is low.

The chemical composition of this alkaline compound is $Na_2Al_2O_4$. It removes carbonate and non-carbonate hardness. It is a very costly coagulant compare to other coagulant aids. It does not increase the permanent hardness of water, removes corrosive quality of water and acceptable for treating water meant for boilers or for water in which aluminum sulphate flocs are not easily formed. Its effective pH range is 6.0 to 8.5. Its chemical equations are:

$Na_2Al_2O + CaSO_4 \rightarrow CaAl_2SO_4 + Na_2SO_4$
$Na_2Al_2O_4 + Cacl \rightarrow CaAl_2O_4 + 2NaCl$
$Na_2Al_2O_4 + Ca(HCO_3)_2 \rightarrow CaAl_2SO_4 + NaCO_3 + CO_2 + H_2O$

To find out the quality of alum required to treat 18 million litres of water per day with the dosage of alum being14mg per litre. Also to find the amount of CO_2 released per litre of treated water, we then will get;

Quantity of alum/day = $\frac{14 \text{ x } 18 \text{ x } 10^6}{10^6} = 252kg$

Considering its chemical reactions;

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

Calculating the molecular weight of alum;

Al_2 $(SO_4)_3$ H O

(2 x 26.97) + (3 x 32.066) + (36 x 1.008) + (30 x 16)

= 53.94 + 96.198 + 36.288 + 480 = 66mg

And also calculating the molecular weight of CO_2

C O

(1 x 12) + (2 x 16) = 44mg

Hence 666mg of alum releases 6 x 44mg of CO_2

Therefore, 14mg of alum will release $\frac{14 \text{ x } 6 \text{ x } 44}{666} = 5.55$mg of CO_2

Flocculation

The term used to denote the process of floc formation is called **flocculation**. Severe agitation is developed in the mixture to obtain a thorough mixing after a coagulant is added to the raw water. Several agitation process is also referred to as the mixing process. After severe agitation mixture is kept slowly agitated for up to 30 to 60 minutes, then coagulants get necessary contact opportunity and then develop flocs during this said period. Even when flocs are seen developed, the mixture is still kept slowly agitated to increases opportunity for contact. The slow agitation of mixture that leads to flocs formation after the vigorous agitation is called **flocculation**. Flocculation chamber is the tank or basin in which flocculation process is carried out. The flocculation chamber's velocity of flow should be kept between 12cm/sec to 18cm/sec.

To speed up flocculation, the following agents could be used.

i. Non-activated sodium silicate which should be introduce directly into the water.
ii. Bentonite
iii. Kieselguhr or infusorail earth (siliceous sedimentary rock)
iv. Certain types of clays
v. Activated carbon in powder form
vi. Precipitated calcium carbonate

Activated silica is a flocculation accelerator which make it possible to obtain a more bulky and heavier flocs. Its addition to water must be after or before the usual coagulants. Activated silica usage makes it possible to increase the efficiency of the settling tanks and do also improve the quality of the clarified water, and then consequently prolong the period between filter washes.

Filtration

Considering pervious topics, we now know that suspended solids are remove from water through screening of water and the sedimentation process. We know also that residual suspended matter is remove from water through the use of coagulant agent such as aluminate sulphate (alum) through the coagulation process of the purification of water. But in all these, processes of screening, sedimentation and coagulation of purification of water, there still remains some fine floc particles and some other suspended matter that only the filtration process can remove. The filtration process of water also reduces the bacteria, content in the water. More purposes of water filtration is to ensure safe clear and attractive water. The process involves passing water through filters. The filters consists of thick layer of sand and when water is filled over it, it gets percolated through it. During the percolation period the water is purified.

Quality of Sand for Filtration and Filter Material

In 1829, James Simpson developed the slow sand filter for a company called Chilsea water company in England. This method of filtration is hardly in use due to its very slow rate of filtration. Between 1900 to 1910, the rapid sand filter was developed in the United States of America. Its rate of filtration is enormously very high hence it is preferred for the filtration of water till date. The filtration process is the most important part of water purification. The sand to be considered for use must be free from loam (soil consisting of sand, silt and a lesser quantity of clay), clay. Lime, vegetable matter, organic impurities and any other unwanted elements. Effective size of sand should indicate the size of sieve in millimeters that will allow the passage of 10% of the sand sample by weight. The choice of effective sand size is important because too fine sand will get clogged in a very short time while too course sand will permit suspended particles and bacteria passage (see table 1.4). There are other types of filters which have low handling cost, give higher filtration rate, durable and more efficient. An example is the anthracite which is stone-coal and burns without smoke or flame. But is widely preferred and mostly used due to its availability everywhere. The uniformly coefficient of sand is the ratio of sieve size in mm through which 60% of the sample of sand by weight will pass to the effective size of sand.

For instance, if we consider an effective size of sand to be 0.40mm, then if 60% of sand from the same sample passes through 0.50mm sieve, then;

Uniformity coefficient $= \frac{0.50}{0.40} = 1.25$

Table 1: Filter sand grain size distribution by % size

Size	Grain size in mm					
	Fine		**Medium**		**Coarse**	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1	0.26	0.32	0.34	0.39	0.41	0.45
10	0.35	0.45	0.45	0.55	0.55	0.65
60	0.53	0.75	0.68	0.91	0.83	1.08
99	0.94	0.50	1.19	1.80	1.46	2.0

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Uniformity coefficient sand for slow sand filters is between 2 and 3 but for rapid sand filters, it varies from 1.20 to 1.70

Classification of filters

There are mainly two types of filters (gravity and pressure) classified on the basis of the rate of filtration but if the rate of filtration basis is considered, there are three types of filters and which are:

i. Slow sand filters
ii. Rapid sand filters
iii. Pressure filters

Filters are generally either gravity or pressure filters. The gravity filters includes the slow sand and rapid sand filters.

The filters can be divided as follows if based upon the consideration of gravity and pressure.

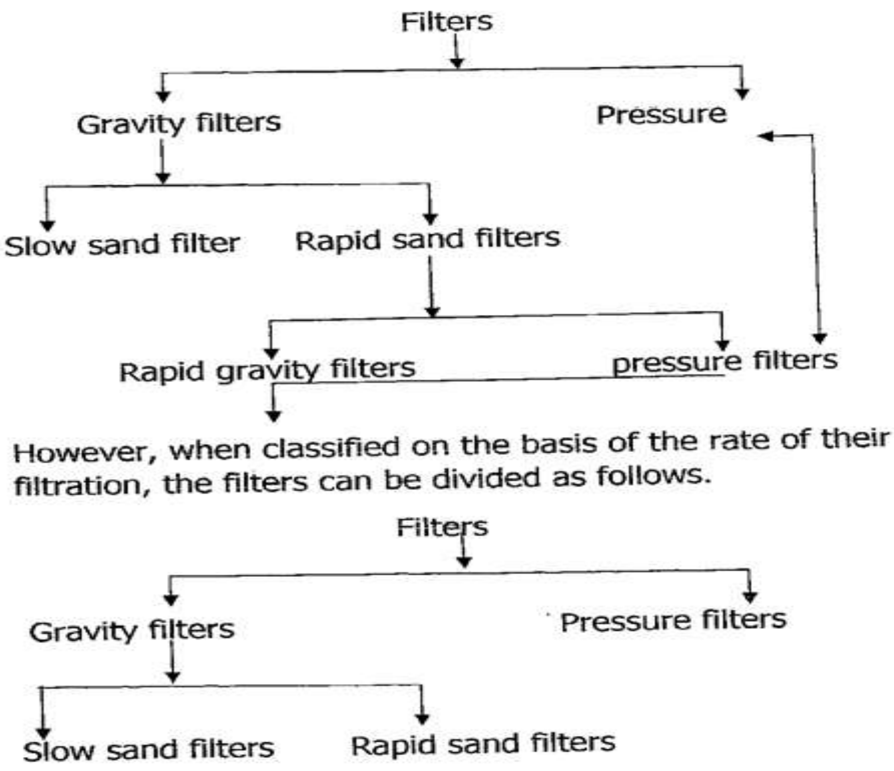

Figure 4: Classification of Filters

The process theory of filtration

Filtration process is the most important part of water purification. The process consist of passing water through a thick layer of sand during which the following effects due to the action of water passage takes place.

i. Any fine suspended and colloidal matter which may be present in water is removed almost completely.
ii. The chemical characteristic of water get changed
iii. Bacteria numbers are considerably reduced.

The purification phenomena of filtration can be well explain on different four processes actions and which are:

a. **Mechanical straining:** Particles present in water and which are suspended and are bigger in size compare to the size of voids and therefore get arrested in them. This means that sand consists of smaller voids and water percolates through the suspended particles which are unable to pass through the voids, they get arrested and are by the action of mechanical straining.
b. **Flocculation and sedimentation:** Voids between the sand particles act as small sedimentation basins. Particles of impurities settle in the voids as a result of the following actions.

i. Because of physical attraction between impurity particles and sand particles, sand particles adheres to impurity particle.
ii. Again due to the presence of gelatinous coating formed on the sand particles by previously caught bacteria and colloidal

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matter, impurity particles adhere to sand particles and are therefore eliminated.

c. **Biological metabolism:** The development of living cell and life process of living cell is known as biological metabolism. Certain bacteria and micro-organisms are generally present in the voids of the filtration which may initially reside as coating over sand grains or they may be caught during the initial process of filtration. However, these organism requires organic impurities such as algae, plankton or other bacteria as their food for their survival. These organisms utilizes such organic impurities and convert them into harmless compounds by the process of biological metabolism. The harmless compound so formed, generally form a layer on the top which is called **schmutzdecke** or also referred to as dirty skin.

d. **Electrolytic charges:** The ionic theory can also be used to explain the filtration process. In this theory, when two substances with opposite electric charge are brought into contact with each other, the electric charges get neutralized which causes new chemical substances to be formed. After a while, electric charge of the filter sand gets exhausted and it becomes necessary to clean the filter, by washing the filter, the electric charge of the filter sand is renewed.

Washing the Filter

When the filtering medium becomes so dirty that the maximum gravity head to force the water through the filter becomes excessive, then the filter unit has to be washed. The reasons or purpose of washing is to remove all suspended materials that has collected on and in the sand from the filter bed. The process of washing involves reversing the flow of water through the filter but with the use of higher rate as much as 60cm per minute in most plants though in some plants higher rates of up to 150cm per minute are use occasionally. A 60cm rate is attained by applying the wash water at the rate of 70 liters per minutes per square meter of filter area. The filtered water used for washing could be supplied from an elevated tank or other source provided that at least 700 litres and preferably more should be available per square meter of filter area to be washed.

The expansion of the sand bed required tosuspend the entire layer depend on the grain size and the specific gravity of the material which is 2.65. In any case however, if the variation in size between top and bottom grains is considerable, the top of the sand must be lifted materially before the bottom grains are suspended. An expansion of about 50% represents good practice in washing but the rate of wash needed to accomplish this varies with the viscosity of the water, which is a function of the temperature. The required wash water rise for equal expansion of the bed will be from 1.5 to 1.6 times as great as 21^0C at 0^0C but depending on the sand size. Required time for washing could be 5 to 10 minutes. And after a unit has been washed, it is again operated normally while making sure that the water from it is allowed to run to waste for 3 to 5 minutes. Sand filters are clean by the application of the following chemicals: caustic soda, soda ash, sulphuric acid, chlorine and sulphure dioxide. They wash away any gelatinous sticky film from the particles and make them free from it. Let us look at a situation where

1. A filter has an area of $36m^2$. If washing for 5 minute at the rate of 60cm per minute is contemplated, how much wash waster will be required?
2. And when a rapid sand filter operating at 90 litre/m^2/minute needs washing after 24 hours of operation. Using the basis in (1) above what percent of the water that is filtered will be required as wash water?

Then,

1) We know that at the rate of 10cm/minute, the quantity of wash water required per square metre = 700 litres

Requirement for $36m^2$ = 36 x 700
= 25,200 litre per minute

Hence total wash water in 5 minutes = 25200 x 5 = 126000 litre

2) Total water filtered in a day = 90 x 35 x 60 x 24 litre
= 4,536,000litre

Water required for wash = 126000 litre [from (1)]

Percentage of wash water $= \frac{126000}{4,536,000} \times 100 =$ 2.8%

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Table 2: Comparison between Slow sandFilter and Rapid Sand Filter

S/N	Slow sand filters	Rapid sand filters (gravity type)
1.	Base material size varies from 45 to 2mm	Base material size varies from 50 to 2mm
2.	Depth of base material is 20cm to 30cm	Depth of base material is 45cm to 50cm
3.	Water coming to the filter need not be coagulated	It is essential that the water be properly coagulated
4.	It requires large area for its installation	Require relatively small area for installation
5.	Its construction is very simple	Its contraction is complicated
6.	It costs more in respect of land and materials	It is cheap in respect of land and material
7.	They are very efficient in the removal of bacteria but less efficient as far as colour and turbidity removal is concerned	They are relatively less efficient in the removal of bacteria but more efficient in the removal of colour and turbidity
8.	Sands effective size varies from 0.20 to 0.30mm and uniformity coefficient is about 1.75 to 2.0	Effective size varies from 0.45 to 0.7mm and uniformity coefficient should not exceed 1.7
9.	Loss of head is 10cm to 125m	Loss of head is below 2.0 to 3.0m
10.	It is cleaned by scraping the top 1.5cm to 2.5cm layer of sand	It is clean by requiring agitation or back washing with or without compressed air
11.	it takes lot of time to clean	it is very quick and washing may be done within 15 minutes
12.	Period of cleaning varies from 1 to 3 months	It varies from 1 to 2 days
13.	Rate of filtration is 100 to 150 litre/hour/m^2 of filter area	Rate of filtration is 100 to 150 litre/minutes/m^2f filter area.
14.	Skilled supervision is not required	Skilled supervision is essentially required
15.	It is suitable for small towns and villages and can be made from local labour and material	It I suitable for big cities

Double Filtration

When water is filtered twice, more satisfactory result is achieve and this is known as double filtration. The process is by filtering water successively through two slow sand filters or through two rapid sand filters or first through rapid sand filter and then through slow sand filter. The rapid sand filter is known as roughing filter in this system of double filtration.

Waste Disposal from Water Treatment Process

So as to protect the sanitation of the environment, disposal of waste from water treatment plants is absolutely necessary and important. The following are some of the ways in which sludge emanating as a result of treatment process could be disposed.

1. Sludge from water treatment plant maybe discharged into any nearby existing sewers.
2. Sludge maybe spread on sand beds for dewatering and then dewatered sludge may be used for filling the low lying areas.
3. It may be discharged in lagoons (open pits) and then used for land fill
4. It may be discharged back into the river in deep waters.
5. Sludge from clarification units using iron and aluminum coagulants can be dewatered by vacuum filtration using lime as the conditioner then, it can be trucked for land fill easily.

Disinfection and Miscellaneous Treatment of Water

We are now aware that sedimentation removes suspended impurities, sedimentation aided by coagulation reduces suspended, colloidal and bacterial impurities to a very large extent. And that filtration removes all sorts of impurities. These impurities may be grouped into the following categories:

a. Colour, taste and odour
b. Dissolved inorganic salts
c. Iron and manganese
d. Bacteria

Elimination of Bacteria Impurities by Disinfection

Disinfection is also known as sterilization of water, but with a difference. The difference is that sterilization is a process of complete destruction of all sorts of bacteria whether harmful or useful to the health of consumers or end users but disinfection restricts its destructive effect to only harmful bacteria. So disinfection by definition, is the process of killing harmful pathogenic bacteria from water and making it safe to the consumers. To enable water remain safe for drinking till it reaches the consumers, the disinfection effect should be for prolonged times. Disinfectants are the materials which are used for disinfection n of water and are expected to be harmless, unobjectionable, economical and not only that, they are available but easy application usage.

Chlorine is the universal most used disinfectant. Chlorination is the process of applying chlorine to water. Chlorine is unobjectionable, economical and harmless to human health. Other methods of disinfection of water which carry no importance as far as disinfection of water on large scale is concerned are:

a) Boiling of water
b) Ozone gas treatment
c) Excess lime treatment
d) Iodine and bromine treatment
e) Ultra violet ray treatment
f) Silver treatment
g) Potassium permanganate (KM_nO_4). (KM_nO_4) is also known as pinkie or candy's fluid.

a) **Boiling**

Water gets disinfected when it is boiled for up to 15 to 20 minutes. Taste is changed, harmful bacteria are killed. Though boiling of water on a large scale is not practicable, consumers are advised to boiled water before use in the case of epidemic breakout.

b) Ozone (O_3) Gas Treatment

Nascent oxygen is produced when ozone combine with organic matter and is effective in the removal of bacteria, it does not produce taste or odour but it is very costly and cannot be used on large scale treatment of water and even as it is unstable and cannot be stored for larger times.

c) Excess Lime Treatment

Lime is known to be a removal of dissolved gases when lime treatment is given to water. But it has been discovered that when excess lime is added to water it work as a disinfectant because it increases the pH value of water which is detrimental to bacteria. After disinfection, the excess lime is removed by process of recarbonation.

d) Iodine and Bromine Treatment

Iodine and bromine are available in form of pills or pallets. They are expensive. They also develop taste and odour not acceptable to consumers. They are good to use in swimming pools, army troops during wars and private plants for some specific purpose.

e) Ultra Violet Rays Treatment

When electric currents is passed through mercury vapour quartz bulbs, ultra violet rays are developed. It is costly and could be used in swimming pool and some private institution's water needs. Ultra-violet rays will not be effective for disinfection purposes if the turbidity and colour of water is more than 15ppm.

f) Silver Treatment

When silver in metallic form is placed as filter media and water while passing through it absorbs some silver and it gets disinfected. It is costly, does not develop odour or taste nor does it cause harmful effects on human body.

g) Potassium Permanganate (KM_nO_4)

Its other name is pinkie or candy's fluid. It has been in use since ancient times mainly for disinfecting the village wells and ponds. It kills cholera bacteria effectively but not quite effective in killing other disease producing organism. Dark brown coating on porcelain vessels are produced though easily noticeable but are very difficult to remove without scratching. It is not recommended for urban cities' water supply scheme.

Good Disinfectant Requirements

A good disinfectant have the following requirements

i. Should be available in enough quantity
ii. Must be economically beneficial
iii. It has to be able to destroy all harmful bacteria and other organisms from water.

iv. Disinfection should be quick and immediate as soon as it has mixing contact with water.
v. The water should not become toxic or carry objectableodour and taste.
vi. Disinfectant's dose should be such that there is always some residual concentration for protection of water from contamination during storage and conveyance through the distribution mains up to the end user's system layout.

Methods of Disinfection

The following are the methods of disinfection of water

a) Boiling of water
b) Ozone gas treatment
c) Excess lime treatment
d) Iodine and bromine treatment
e) Ultra violet ray treatment
f) Silver treatment
g) Potassium permanganate (KM_nO_4) treatment
h) Chlorination

II. CONCLUSION

Water available in raw form must be treated and purified first before supplying it to the general public for domestic, industrial or any other uses. The methods or techniques processes accepted for purifying the public water supplies include the following;

a) Screening
b) Plain sedimentation
c) Sedimentation aided with coagulation
d) Filtration
e) Disinfection
f) Aeration
g) Softening
h) Miscellaneous treatment (fluoridation, recarbonation, liming, desalination e.t.c)

All the techniques above could or may not be used for treating a particular water. The necessity of a few or all of these treatments depends solely upon the quality of the available raw water. Most of the big visible objects like tree branches, sticks, vegetations not alive again, fishes and animals not alive again can be physically removed from the water. The process of doing this is called **screening.** Impurities present in raw water's suspended materials can then be eliminated by allowing the water settle in sedimentation basins or bottom platforms. The process of doing this is called **plain sedimentation**. The effectiveness of sedimentation may be increased when certain chemicals are mixed with the water which will then form flocculent precipitate (flocculation) carrying the suspended particles as it settles. This process is called **Chemical Coagulation**. This finer particles is suspended even after using chemical coagulation and are then removed by filtering the water through filters. This process is called **filtration**.

The filtered water which may still contain pathogenic bacteria is then made bacteria proof by adding certain chemicals such as chlorine. Again this process of eliminating or killing of germs is called **disinfection** through an appropriate addition of chlorine, a process which is known as **chlorination**. The resulting disinfected water though safer now, but may not be attractive yet to the consumers. Unpleasant tastes and odours may then thus have to be removed by adding certain chemical compounds such as activated carbon or by using ozone. This process is called **aeration**. The resulting water may sometimes be much harder than permissible and therefore have to be softened by a process called **softening**.

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