industrial and commercial purposes. Some of the water is always stored for fire fighting. As there is a depletion of ground water, and uncertainty of rainfall due to global warming and other reasons, it has become very difficult to maintain the urban water supply schemes these days.

2.6.1 Quality of Water

Quality of water is the most important aspect. There are international and national standards for the quality of water to be supplied for human consumption. The state governments may have a slight relaxation in the standards depending upon the local conditions but in general they are the same throughout the country.

The main aim of the public health engineering departments or the environmental engineering departments as they are called these days is to supply safe and palatable (good in taste) water to the consumers. Water should also be free from any odour. The temperature of water should be reasonably good. It should neither be corrosive nor scale forming and should be free from minerals that can produce undesirable physiological effects. For achieving this ideal condition the minimum standards of quality are to be established. The evolution of standards for the control of quality of public water supplies has to consider the limitations imposed by the local factors in the different regions of the country. As per the Manual on Water Supply and Treatment published by the Government of India, the main objective is to make water absolutely free from risks of transmitting disease, means safety is compulsory where as the other qualities are to be maintained within a specified range. For example water may have dissolved solids upto 500 mg per litre but cannot have any bacteria or other micro organism. Actually water is a very good carrier of many diseases producing organisms (pathogens) as there are all chances of its getting contaminated (infected by pathogens). If a small drop of urine or fecal matter (excreta, nightoil) is mixed in a body of water (canal, pond etc.) and the person contributing it has some disease like cholera, gastroentitis, infectious hepatitis jaundice, typhoid, etc., it will infect the stream. Anybody using that water without treatment (disinfection) is liable to catch the same disease. Sometimes the foul waste water (from latrines, toilets etc.) goes down the earth and gets mixed (at a shallow depth) with the ground water it pollutes it. If this ground water lifted by a hand pump or a tube-well is used again without disinfect ion it shall cause disease in the person using it. Sometimes the dissolved salts may produce some other diseases like fluorosis (due to excessive fluoride) mathemaglobinemia (blue baby disease) due to excessive nitrates in, infants) etc. So water must not have the physical, chemical and bacteriological parameters beyond limits.

(a) The following table shows the physical and chemical standards of water as per the manual.

Table 2.2 Physical and Chemical Standards

S. No.	Characteristics	*Acceptable	**Cause for rejection
1	Turbidity (units on J.T.U. Scale)	2.5	10
2	Colour (Units on platinum Cobalt Scale)	5.0	25
3	Taste and Odour	Unobjectionable	Unobjectionable
4	pH	7.0 to 8.5	6.5 to 9.2
5	Total dissolved solids(mg/l)	500	1500
6	Total hardness (mg/l)(as $CaCO_3$)	200	600
7	Chlorides as Cl (mg/l)	200	1000
8	Sulphates (as SO_4) (mg/l)	200	400
9	Fluorides (as F) (mg/l)	1.0	1.5
10	Nitrates (as NO_3) (mg/l)	45	45
11	Calcium (as Ca) (mg/l)	75	200
12	Magnesium (as Mg) (mg/l)	30	150
13	Iron (as Fe) (mg/l)	0.1	1.0
14	Manganese as Mn (mg/l)	0.05	0.5
15	Copper (as Cu) (mg/l)	0.05	1.5
16	Zinc as Zn (mg/l)	5	15
17	Phenolic Componds (as Phenol) mg/l	0.001	0.002
18	Anionic detergents (as MBAS) (mg/l)	0.2	1.0
19	Mineral Oil (mg/l)	0.01	0.3

Table 2.3 Toxic Materials

S. No.	Characteristics	Acceptable	Cause for rejection
1	Arsenic (as As) (mg/l)	0.05	0.05
2	Cadmium (as Cd) (mg/l)	0.01	0.01
3	Chromium (as hexavalent Cr) (mg/l)	0.05	0.05
4	Cyanides (as CN) (mg/l)	0.05	0.05
5	Lead (as Pb) (mg/l)	0.1	0.1
6	Selenium (as Se) (mg/l)	0.01	0.01
7	Mercury (total as Hg) (mg/l)	0.001	0.001
8	Polynuclear aromatic hydrocarbons (PAH)	0.2m g/l	0.2m g/l

Contd....

Radio Activity			
1	Gross Alpha activity	3 pico curie/l	3 pico curie/l
2	Gross Beta activity	30 pico curie/l	30 pico curie/l

Notes *The figures indicated under the column 'acceptable' are the limits upto which the water is generally acceptable to the consumer.

**Figures in excess of those mentioned under "acceptable' render the water not acceptable, but still may be tolerated in the absence of alternative and better source but upto the limits indicated under column "cause for rejection" above which the supply will have to be rejected.

It is possible that some mine and spring water may exceed these radio activity limits and in such case it is necessary to analyze the individual radionuclides in order to assess the acceptability or otherwise for public consumption.

(b) Bacteriological Standards

(i) **Water entering the distribution system:-**

Coliform (bacteria, as the indicator organism) count in any sample of 100 ml water should be zero. A sample of the water entering the distribution system that does not conform to this standard calls for an immediate investigation into both the efficacy of the purification process and the method of sampling.

(ii) **Water in the distribution system shall satisfy all the three criteria indicated below:-**

- E. Coli (Escherichia Coli, bacteria found in the colon of human beings as a natural habitant) count in 100 ml of any sample should be zero.
- Coliform organisms (group of B- Coli bacteria coli and E. Coli) , not more than 10 per 100 ml shall be present in any sample.
- Coliform organisms should not be detectable in 100 ml of any two consecutive sample or more than 5% of the samples collected for the year.

If coliform organisms are found, re-sampling should be done. The repeated findings of 1 to 10 coliform organisms in 100 ml or the appearance of higher numbers in any sample should necessitate the investigation and removal of the source of pollution.

(iii) **Individual or small community supplies**

E.coli count should be zero in any sample of 100 ml and coliform organisms should not be more than 3 per 100 ml. (If repeated samples show the presence of coliform organisms, steps should be taken to discover and remove the source of pollution. If coliform exceeds 3 per 100 ml, the supply should be disinfected).

(c) *Virological Aspects*

0.5 mg/l of free chlorine residual for one hour is sufficient to inactivate virus, even in water that was originally polluted. This free chlorine residual is to be insisted in all disinfected supplies in areas suspected of endemicity of infectious hepatitis Jaundice to take care of the safety of the supply from virus point of view which incidentally takes care of the safety from the bacteriological point of view as well. For other areas 0.2 mg/l of free chlorine residual for half an hour should be insisted.

2.6.2 Characteristics of Water

To ensure the quality of safe drinking water (potable water) the water is to be tested for its physical, chemical and bacteriological characteristics.

(a) Physical Characteristics:

(i) **Temperature:** It can be measured by a thermometer. The temperature should be suitable to the human beings depending upon the climatic and weather conditions. An average temperature of 15°C is generally suitable.

(ii) **Turbidity:** The muddy or cloudy appearance of clay or such other particles that presents hindrance to the path of light is known as turbidity. It may not be harmful but even then from aesthetical point of view it should not exceed the allowable value. The turbidity is measured by a turbidity rod or a turbidity meter with physical observations and is expressed as the suspended matter in mg/l or ppm (part per million). The standard unit of turbidity is that which is produced by 1 mg of finely divided silica in one litre of distilled water. The turbidity in excess of 5 mg/l is detectable by the consumer and is hence objectionable. It is measured in the laboratory by **Jackson** , **Baylis** or such other turbiditymeters.

(iii) **Colour:** The colour is imparted by dissolved organic matters from decaying vegetation or some inorganic materials such as coloured soils (red soil) etc. The algae or other aquatic plants may also impart colour. Again it is more objectionable from aesthetics point of view than the health. The standard unit of colour is that which is produced by one milligram of platinum cobalt dissolved in one liter of distilled water. Colour is measured in the labs by **Nessler's tubes** by comparing the sample with the known colour intensities. More precisely tintometer measures it.

(iv) **Taste and odour:** The dissolved inorganic salts or organic matter or the dissolved gases may impart taste and odour to the water. The water must not contain any undesirable or objectionable taste or odour. The extent of taste or odour is measured by a term called odour intensity which is related with threshold odour, which represents the dilution ratio at which the odour is hardly detectible. The water to be tested is gradually diluted with odour free water and the mixture at which the detection of taste and odour is just lost is determined. The number of times the sample is diluted is known as the threshold number. Thus if 20 ml of water is made 100 ml (until it just looses its taste or odour) then the threshold number is 5. For domestic water supplies the water should be free from any taste and odour so the threshold number should be 1 and should not exceed 3.

(v) **Specific conductivity of water:** The specific conductivity of water is determined by means of a portable dionic water tester and is expressed as micro-mhos per cm at 25°C. Mho is the unit of conductivity and is equal to 1 amper/1 volt). The specific conductivity is multiplied by a co-efficient (generally 0.65) so as to directly obtain the dissolved salt content in ppm..

(b) Chemical Characteristics

Chemical analysis of water is done to determine the chemical characteristics of water. This involves the determination of total solids, suspended solids, pH value, hardness, chlorides, nitrogen content, iron, manganese and other contents, dissolved gases etc.

(i) **Total solids and suspended solids:** The total amount of solids can be determined by evaporating a measured sample of water and weighing the dry residue left. The suspended solids can be determined by filtering the water sample and weighing the residue left on the filter paper. The difference between the total solids and the suspended solids will be the dissolved solids.

(ii) **pH of water:** pH is the negative logarithm of hydrogen ion concentration present in water. The higher values of pH mean lower hydrogen ion concentrations and thus represent alkaline water and vice versa. The neutral water has same number of H^+ and OH^- ions. The concentration of both ions in neutral water is 10^{-7} moles per liter. The neutral water will therefore possess a pH equal to

$$\log_{10}(1/H^+) = \log_{10}(1/10^{-7}) = \log_{10} 10^7 = 7$$

If an acid is added to neutral water the number of hydrogen ion increases and thus the pH reduces. Similarly, if an alkali is added the number of hydroxyl ion increases thus reducing the hydrogen ion (as their product is constant, = 10^{-14} mole/liter) and the pH increases.

Hence, if the pH of water is more than 7 it is alkaline and if it is less than 7 it is acidic. Generally, the alkalinity in water is caused by the presence of bicarbonates of calcium and magnesium, or by the carbonates or hydroxides of sodium potassium calcium and magnesium. Some of the compounds which cause alkalinity also cause hardness. Acidity is caused by the presence of mineral acids, free carbon dioxide, sulphates of iron and aluminium etc.

The pH value can be measured by a digital pH meter. It can also be measured with the help of colour indicators. The indicators are added to sample of water and the colour produced is compared with the standard colours of known pH values.

For municipal water supplies the pH should be as close to 7 as possible. The lower pH water (acidic) may harm the pipe lines etc. by reacting with them (tuberculation and corrosion). The alkaline water may produce sedimentation, (scaling) in pipes, difficulties in chlorination (for disinfection) and adverse effect on human physiological system.

(iii) **Hardness of water:** Hardness in water prevents the formation of sufficient foam when used with soap. It is caused by certain dissolved salts of calcium and magnesium which form scum with soap and reduce the formation of foam which helps in removing the dirt from clothes. These salts keep on depositing on the surface of boilers and thus form a layer known as scale which reduces the efficiency of the boilers. The hardness is known as temporary hardness if it is due to the bicarbonates of calcium and magnesium as this can be easily removed by boiling water or adding lime to it. By boiling the carbon dioxide gas escapes and the insoluble carbonates are deposited (which cause scaling). If sulphates, chlorides and nitrates are present they cannot be easily removed by boiling and so such water requires water softening methods and this type of hardness is known as permanent hardness.

Hardness is measured by titration method (E.D.T.A. method) and is expressed in ppm or mg/l. Generally the underground water is more hard as it dissolves the salts in its journey from surface to the ground water table. For boiler feed waters and for efficient washing of clothes the water must be soft i.e. hardness should be less than 75 ppm(mg/l).

(iv) **Chlorides:** Chlorides are generally present in water in the form of sodium chloride and their concentration above 250 mg/l produces a salty taste in drinking water. The chlorides can be measured in water by titrating the water with standard silver nitrate solution using potassium chromate as indicator.

(v) **Nitrogen content:** The nitrogen in water may occur in one or more forms of the following:

(a) Free ammonia
(b) Albuminoid nitrogen
(c) Nitrites
(d) Nitrates

The free ammonia indicates very fast stage of decomposition of organic matter (thus indicating fresh pollution); albuminoid nitrogen represents the quantity of nitrogen present in water before the decomposition of organic matter has started, the nitrites indicate the partly decomposed organic matter (the continuation of decomposition) and the nitrates indicate the presence of fully oxidized organic matter (means the prior pollution condition). In potable water the free ammonia (undecomposed organic matter should not be more than 0.15 ppm, and the albuminoidal nitrogen should not be more than 0.3 ppm. The nitrogen may remain in the form of nitrates but that too should not be more than 45 ppm as a higher concentration causes blue baby disease in the infants. Actually the nitrates act with the haemoglobin in the blood (which imparts red colour) and reduce it thus converting the colour of skin to blue (impure blood) and thus making them ill and in extreme cases they can die. Nitrate is measured either by reduction to ammonia or by matching the colours produced with phenoldisulphonic acid.

(vi) **Metals and other chemical substances:** Various metals and minerals may be present in water like iron, manganese, copper, lead, cadmium, arsenic, barium, selenium, etc. The allowable limits for them are as shown in the above tables. If the concentration of these metals and minerals exceeds the permissible limits they have certain harmful effects on the human health.

Higher concentrations of iron and manganese may cause discoloration of clothes washed in such waters. They may cause incrustation in water supply pipe lines due to deposition of ferric hydroxide and manganese oxide. Lead and barium salts are toxic and thus very low concentration of these salts is permissible. Arsenic is a well known poison and as such extremely low concentration (0.05 ppm) is permitted. Most of the ground water in Punjab is having arsenic more than the permissible limits because of the industrial waste water pollution. High quantities of copper may badly affect human lungs and other respiratory organs.

(vii) **Dissolved gases:** Various gases like CO_2, O_2, N_2, H_2S and CH_4 etc. may be present in dissolved form in water. H_2S even in small concentration gives bad taste and odour. CO_2 indicates biological activity. Oxygen is generally absorbed by water from the atmosphere. Its saturation concentration depends upon temperature. The organic matter may be present in water due to the disposal of waste water in it. Organic matter is instable and has a tendency to become stable i.e. to be inorganic matter. This conversion is known as decomposition of organic matter and the process is bio-chemical. As it takes place by bacteria (bio means living) and the conversion is extra cellular enzymatic reaction so it is known as a bio-chemical reaction. The demand of oxygen imposed by the aerobic (working in presence of oxygen) bacteria is known as the Bio Chemical Oxygen Demand (BOD). This BOD reduces the dissolved oxygen content of the water. So if the DO of water is found to be less than the concentration DO it indicates the water pollution. The BOD of treated water should be nil.

After knowing the standards of potable water one should know the ways and means to make the water fit for drinking, i.e. the treatment of water.

2.7 TREATMENT OF WATER

The available raw water has to be treated to make it fit, i.e. potable, means safe for human consumption. It should satisfy the physical, chemical and bacteriological standards as specified above. The various methods of purification of water are

(i) Screening
(ii) Plain sedimentation
(iii) Sedimentation aided with coagulation
(iv) Filtration
(v) Disinfection
(vi) Aeration
(vii) Softening
(viii) Miscellaneous treatments like defluoridation, recarbonation desalination etc.

2.7.1 Screening

Screens are provided before the intake works so as to prevent the entry of big objects like debris, branches of trees, part of animals etc. Screens may be of two types, coarse screen and fine screens. Coarse screens are parallel iron rods placed vertically or at a small slope at about 2.5 cm to 10 cm apart. The fine screens are made up of fine wire or perforated metal with small openings less than 1 cm size. Finer is the screen more are the chances of clogging so generally only coarse screens are used. The screens may be manually cleaned or mechanically cleaned depending upon the requirement i.e. the size of the treatment plant.

2.7.2 Plain Sedimentation

Sedimentation is done to remove the impurities which have specific gravity more than that of water and are settleable. When water is moving these impurities remain in suspension due to the turbulence and as the velocity is reduced they settle down. It is not necessary to stop the motion of water completely as it will require more volume of the sedimentation tanks. As per the theory of sedimentation the settlement of a particle depend upon the velocity of flow, the viscosity of water, the size shape and specific gravity of particle. The settling velocity of a spherical particle is expressed by Stoke's law which gives the final equation as follows,

$$V_s = g/18 \ (S_s-1)\ d^2/\upsilon$$

Where V_s = Velocity of settlement of particle in m/sec

d = diameter of the particle in cm

Ss = specific gravity of the particle

υ = kinematic viscosity of water in m^2/sec

Knowing the settling velocity of particle, that is intended to be settled, the design of the settling tank is done.

2.7.3 Sedimentation Aided with Coagulation

The fine suspended particles like mud particles and the colloidal matter present in water cannot settle down by plain sedimentation with ordinary (lesser) detention periods. Some of the colloidal impurities will not settle even if the water is detained for long periods in the sedimentation tanks as the same charge on the clay particles repel each other and do not allow them to settle down. So the sedimentation is aided with coagulation. Coagulation is a process in which some chemical like alum or ferrous sulphate is mixed in water resulting in particle destabilization. Operationally this is achieved by the addition of appropriate chemical like alum and intense mixing for achieving uniform dispersion of the chemical. These chemicals are more effective when the water is slightly alkaline. Sometimes sodium carbonate or lime is to be added to achieve the suitable pH of water. Flocculation is the second stage of the formation of settleable particles (or flocs) from destabilized (neutral) colloidal particles and is achieved by gentle (slow) mixing. So in flocculation the alum is first mixed rapidly for dispersion and then slow mixing produces flocks. Both these stages of flocculation are greatly influenced by physical and chemical forces such as electrical charge on particles, exchange capacity, particle size and concentration, pH, water temperature and electrolyte concentration.

2.7.4 Filtration

Filtration is a physical and chemical process for separating suspended and colloidal impurities from water by passage through a porous bed made up of gravel and sand etc. Actually the sedimentation even aided with coagulation and flocculation cannot remove all the suspended and colloidal impurities and to make water (specially surface water) fit for drinking filtration is a must. The theory of filtration includes the following actions:

- Mechanical straining, the suspended particles present in water that are of bigger size than the voids in the sand layers are retained their itself and the water becomes free of them. The sand layer may get choked after some time and then it is to be cleaned for further action by washing it back.
- Sedimentation, the small voids in the sand act as tiny sedimentation tanks and the colloidal matter arrested in these voids is a gelatinous mass and thus attracts other finer particles. These finer particles are thus removed by the sedimentation.

- Biological metabolism, certain micro-organisms are present in the sand voids. They decompose the organic matter like the algae etc. and thus remove some of the impurity.
- Electrolytic change, according to the theory of ionization a filter helps in purifying the water by changing the chemical characteristics of water. The sand grains of the filter media and the impurities in water carry electrical charge of opposite nature which neutralizes each other and forces the paticles to settle now by gravity.

2.7.5 Disinfection

The filtration of water removes the suspended impurities and removes a large percentage of bacteria but still some of the bacteria remain there in the filtered water. This bacteria may be harmful bacteria (disease producing bacteria) known as pathogenic bacteria. The process of killing these bacteria is known as disinfection. There are many diseases like cholera, gastro entities, infectious hepatitis (jaundice), typhoid etc., the bacteria or virus of which transmits through water. It is necessary to make water free from any micro-organism before human consumption. Contamination (mixing of pathogenic micro-organism) may take place in the water supply at any time (because of leakage etc.) so proper measures must be taken to stop it at all levels. Generally the disinfection is done by adding chlorine to water. There should be a residual amount of chlorine after the disinfection to fight with any probable contamination in the route of water to the consumer. Following are some of the methods of disinfection

- Boiling of water
- Treatment with excess lime
- Use of ozone
- Treatment with ultraviolet rays
- Use of potassium permanganate
- Treatment with silver
- Use of bromine, iodine and chlorine

Out of the above, treatment with chlorine is the most popular and economically effective. Actually the criteria for a good disinfectant as per the Manual are,

- It should be capable of destroying the pathogenic organisms present, within the contact time available and not unduly influenced by the range of physical and chemical properties of water encountered particularly temperature, pH and mineral constituents.
- It should not leave products of reaction which render the water toxic or impart colour or otherwise make it unpotable.
- It should have ready and dependable availability at reasonable cost permitting convenient, safe and accurate application to water.

- It should possess the property of leaving residual concentrations to deal with small possible recontamination.
- It should be amenable to detection by practical, rapid and simple analytical techniques in the small concentration ranges to permit the control of efficiency of the disinfection process.

The factors affecting the efficiency of disinfection are

- Type, condition and concentration of organisms to be destroyed
- Type and concentration of disinfectant
- Contact time and concentration of disinfectants in water and
- Chemical and physical characteristics of water to be treated particularly the temperature, pH and mineral constituents.

Potable water should always have some amount of **residual chlorine,** as there are all chances of contamination at all levels. This may be 0.2 ppm. to 0.3 ppm. depending upon the requirement (rainy season or enhanced chances, more Cl_2 required). To make sure the presence of chlorine some tests are done out of which Orthotolodine test is the most common one.

Orthotolidine Test: In this test 10 ml of chlorinated sample of water is taken after the required contact period (say half an hour) in a glass tube. 0.1 ml of orthotolidine solution is added to it. The colour formed is noted after 5 minutes and compared with the standard coloured glasses. Darker is the yellow colour formed more is the residual chlorine. The test is very simple and even a semi- skilled employee can perform it satisfactorily and it can be done at the site itself and accordingly corrective measures can be taken. For example if there is a complaint from a hostel mess. Test is performed for the tank water and if no residual chlorine is found, bleaching powder (a good source of chlorine) is mixed with some water and added to the tank water in paste form and stirred. The test is again performed after half an hour till it shows the required residual chlorine.

2.7.6 Aeration

Taste and odour, both are undesirable in water. Aeration is done to remove taste and odour. Aeration is done to promote the exchange of gases between the water and the atmosphere. In the water treatment, aeration is performed for the following purposes,

- To add oxygen to water for imparting freshness, for example water from underground sources may have lesser oxygen.
- For expulsion of carbon dioxide, hydrogen sulphide and other volatile sustances causing taste and odour.
- To precipitate impurities like iron and manganese specially from undeground water.

In aeration gases are dissolved in or liberated from water until the concentration of the gas in the water has reached its saturation value. The concentration of gases in a liquid generally obeys Henery's law which states that the concentration of each gas in water is directly proportional to the partial pressure (product of the volume percentage of the gas and the total pressure of the atmosphere.) or concentration of gas in the atmosphere in contact with water. The saturation concentration of a gas decreases with temperature and dissolved salts in water. Aeration accelerates the exchange of gas. To ensure proper aeration it is necessary to,

- Increase the area of water in contact with the air. The smaller are the droplets produced the larger will be the area available.
- Keep the surface of the liquid constantly agitated so as to reduce the thickness of the liquid film which would govern the resistance offered to the rate of exchange of the gas.
- Increase the time of contact of water droplets with air or increase the time of flow which can be achieved by increasing the height of jet in spray aerators and increasing the height of tower in case of packed media.

Where oxygen is to be dissolved in water, the concentration or partial pressure of the oxygen may be increased by increasing the total pressure of the gas in contact with water. For this purpose air injected into a main under pressure is a reasonably efficient method of increasing the amount of dissolved oxygen.

2.7.7 Water Softening

The reduction or removal of hardness from water is called as water softening. For domestic water supplies the softening is done to reduce the soap consumption, to ensure longer life to washed fabric, to lower the cost of maintaining plumbing fixtures and to improve the taste of food preparations and improve palatability (good taste). For industrial supplies softening is done for reducing scaling problems in boilers and the interference in the working of dyeing systems. Usually a total hardness of 75 to 100 mg/l (as $CaCO_3$) would meet these requirements. The magnesium hardness should not exceed 40 mg/l to minimize the possibility of magnesium hydroxide scale in domestic water heaters. Calcium and magnesium associated with bicarbonates are responsible for carbonate hardness and that with the sulphates, chlorides and nitrates contribute to non carbonate hardness. Normally the alkalinity measures the carbonate hardness unless it contains sodium alkalinity. The non carbonate hardness is measured by the difference between the total hardness and the carbonate hardness. Carbonates and bicarbonates of sodium are described as negative non carbonate hardness.

The temporary hardness or bicarbonate hardness can be removed by boiling or by adding lime. The following reactions take place by boiling:

$$Ca(HCO_3)_2 + Heat = CaCO_3 \downarrow + H_2O + CO_2 \uparrow$$

$$Mg(HCO_3)_2 + Heat = MgCO_3 \downarrow + H_2O + CO_2 \uparrow$$

As it is difficult to boil the water at large scale the addition of lime is done. The following reaction takes place when lime is added to water,

$$Ca(HCO_3)_2 + Ca(OH)_2 = CaCO_3 \downarrow + 2H_2O$$
$$Mg(HCO_3)_2 + Ca(OH)_2 = CaCO_3 \downarrow + MgCO_3 \downarrow + 2H_2O$$

The carbonates of calcium and magnesium are removed by sedimentation being insoluble in water.

The permanent hardness is removed by:

(i) Lime-soda process

(ii) Zeolite process

(iii) Demineralization or deionization process.

Lime-soda process

In the lime soda process lime and soda ash (Na_2CO_3) are added which removes both the temporary and permanent hardness.

The additional reactions with soda are as follows

$$MgSO_4 + Ca(OH)_2 = CaSO_4 + Mg(OH)_2 \downarrow$$
$$Ca\ SO_4 + Na_2CO_3 = CaCO_3 \downarrow + Na_2SO_4$$
$$Ca\ Cl_2 + Na_2CO_3 = CaCO_3 \downarrow + 2NaCl$$
$$Mg\ Cl_2 + Ca(OH)_2 = CaCl_2 + Mg(OH)_2 \downarrow$$

Using the above reactions the hardness is removed in the lime soda plants

Zeolite process

The lime soda method is a precipitation method in which some chemicals or reagents are added to the water. In the zeolite process no such chemical is added and the hard water is passed through a bed of special material called as the zeolite. The zeolite has the property of removing calcium and magnesium from the water and substituting sodium in their place by ion exchange phenomenon. Zeolites are complex compounds of aluminum, silica and soda, some times synthetic and otherwise natural. Natural zeolites are mainly processed from green sand (glauconite). It has an exchange value of about 8000 gm of hardness per m^3 of zeolite. The common artificial zeolite is permutit. It has larger grains with white colour. Permutit (SiO_2 Al_2O_3 Na_2O) has a high exchange value of 35000 to 40000 gm of hardness per m^3 of zeolite.

When hard water passes through a bed of permutit the following reactions take place

$$2SiO_2Al_2O_3\ Na_2O + Ca(HCO_3)2 = 2SiO_2\ Al_2O_3CaO + 2NaHCO_3$$
$$2SiO_2Al_2O_3\ Na_2O + CaSO_4 = 2SiO_2\ Al_2O_3CaO + Na_2SO_4$$
$$2SiO_2Al_2O_3\ Na_2O + CaCl_2 = 2SiO_2\ Al_2O_3CaO + 2NaCl$$

Similar reactions take place with compounds of magnesium hardness can be reduces to almost zero by this method. Due to continuous use of the zeolite the sodium gets exhausted and then the zeolite has to be regenerated by passing a solution of salt through it. The sodium in the brine (salt water) replaces the calcium and magnesium