water is cooled and fresh water is heated. Hot fresh water leaving the highest pressure stage is used to heat in coming sea water. Part of the cooled fresh water is recycled to the lowest pressure stage; the rest is product.

In most processes involving sea water distillation, scaling limits the maximum temperature in the systems. In the vapour reheat system, the absence of heat-transfer surfaces and reduction of scaling problems removes this limitation.

9.8.2 FREEZING

Water can be transposed from saline water to the solid phase as ice. The fact that the latent heat of fusion, viz., 80 Kcal/kg is small compared to the latent heat of vaporization is taken advantage of in this process. However, even though the ice crystals formed constitute essentially pure water, the yield of product water is decreased because some of it is used to wash salt from the ice surfaces and heat is required to melt the ice crystals. As in distillation, countercurrent operation conserves heat energy in this system also. By cooling the feed water to the freezing point before a refrigerant is evaporated in direct contact with the feed and by countercurrent washing and melting of the ice crystals, maximum economy is effected.

(a) Contact Freezing

This makes use of two heat-transfer circuits of recycling hydrocarbons. The first circuit absorbs heat from the incoming salt water, transfers it in part to the fresh water and loses it in part to the waste brine. The second circuit vaporizes the liquid hydrocarbon in contact with the salt water to freeze it; the vapour is then compressed and the heat energy released is used to melt the ice. The vapour separating from the fresh water is repumped through the freeze chamber.

(b) Eutectic Freezing

This operates at the eutectic temperature of the incoming water. Down to the eutectic point only ice is formed. At the eutectic point, ice crystals nucleate and grow independently of salt crystals and other substances in the water, thus permitting separation. Further removal of heat does not continue to lower the temperature.

9.8.3 SOLVENT EXTRACTION

Organic solvents partially miscible with water can be used to extract the fresh water leaving behind a more concentrated salt solution. The solvent fresh water phase can be separated out from the concentrated salt solution and distilled to yield fresh water.

9.8.4 OSMOSIS

Certain natural and synthetic membranes have the property of permitting the solvent (water) to get through them but not the solute. Such semipermeable membranes permit the separation of solute from solvent. This phenomenon is known as Osmosis.

(a) Reverse Osmosis (RO)

Reverse Osmosis is a membrane permeation process for separating relatively pure water (or other solvent) from a less pure solution. The solution is passed over the surface of an appropriate semi permeable membrane at a pressure in excess of the effective osmotic pressure of the feed solution. The permeating liquid is collected as the product and the

concentrated feed solution is generally discarded. The membrane must be highly permeable to water, highly impermeable to solutes, and capable of withstanding the applied pressure without failure. Because of its simplicity in concept and execution, reverse osmosis appears to have considerable potential for wide application in water and waste water treatment.

(b) Electrodialysis (ED)

Unaided osmosis is a relatively slow process and hence attempts have been made to combine this with electrolysis. Application of an external electromotive force can draw the ions away from the salt solution towards the electrodes so that the solution is impoverished of its salt content. The reunion of the ions by diffusion can be prevented by using suitable membranes to separate the cathode and anode chambers and also by continuously removing the relatively concentrated solution of the electrolytes from the electrode chambers. To obtain purification of sufficient magnitude a number of electrolytic cells have to be used in series. In essence the apparatus would consist of a number of electrolytic cells each of which is composed of 3 compartments separated from each other by suitable membranes. The saline water circulates in series through the middle compartments of the cells and undergoes progressive purification. The number of cells and the rate of flow may be adjusted to give the degree of purification required. A direct current of 110 to 220 volts is employed. The electrodes are continuously washed with the treated water. One of the main disadvantages of the electrodialysis process is that the membranes get badly damaged as a result of corrosion and scale formation. Another disadvantage is that the cost goes up steeply as total solids content of the finished water decreases. Power loss is minimized if the water is demineralised only partially to final concentrations of less than 500 mg/l in a multi-compartment cell. Average power requirements are 1 kWh/ m^3 of water/1000 mg/ 1 of TDS removed for waters with initial TDS values of 10,000 and less. Since power requirements rise sharply with higher initial values in this method compared to distillation and freezing, this process is adopted only for waters containing less than 10,000 mg/l of dissolved solids.

(c) Osmionic Process

This process is based on the principle of osmosis through ion-selective membranes which pass only anions or cations preventing the passage of the other ions. The concentration gradient between the solutions supplies the potential required to drive the ions through the ion-selective membranes unlike in the case of reverse osmosis where pressure is applied to force the water but not the salts through the membranes.

9.8.5 Ion-Exchange Process

When a salt solution is percolated through a cation exchange resin treated with acids the effluent contains equivalent amounts of the corresponding acids as shown below:

$$H_2Zc + M^{++} + 2A^- \rightleftharpoons MZc + 2H^+ + 2A^-$$

Where M^{++} is Ca^{++} or Mg^{++} . The same equation can also be written for monovalent ions like Na^+ or K^+.

When this acidic effluent is passed through an anion exchange resin which has been treated with alkali so that it contains replaceable hydroxyl ions, the anions are exchanged for

the hydroxyl ion with the result that the effluent is rendered free from salts as illustrated as follows:

$$Z_A OH + H^+ + A^- \longrightarrow Z_A A + H_2O$$

Thus it is possible to remove salts from brackish water by a process requiring no more technical skill than that involved in the use of percolation columns. The beds could be regenerated and used repeatedly without appreciable loss in capacity.

High capacity cation exchange materials have been discussed in 9.5.2.2. (b). The anion exchange materials have been prepared by condensing substituted aromatic amines with formaldehyde. These ion exchange resins have come to stay in the field of treatment of water for industries and especially in the production of make up water for high pressure boilers. They have also a place in the treatment of brackish water for the production of potable water.

9.8.6 Performance of RO and ED plants

Based on evaluation studies conducted by NEERI on the working of desalination plants employing Reverse Osmosis and Electrodialysis principles, following information emerges:

(a) Recurring cost of desalination by Reverse Osmosis (RO) and Electrodialysis (ED) ranges from Rs. 9 to Rs. 31 and Rs. 8 to Rs. 24 respectively per m^3 (1987). Including depreciation and interest on capital, the cost works out as Rs. 40 to Rs. 131 for RO and Rs. 28 to Rs. 85 in case of ED (1987).

(b) Quality of product water in RO is consistent while it is generally not so in ED.

(c) In spite of elaborate pre-treatment, operation and maintenance, the plants could not yield consistent quality of product water within permissible limits. Whenever such consistency in quality was attempted, the product water recovery decreased considerably, thereby raising the cost of treatment of desalinated water. The reject water quantity correspondingly increased.

(d) In the RO plants evaluated, rated capacity of product water was rarely achieved. In the plants Studied by NEERI, only one produced at 100% capacity, while others functioned at 30,50 and 72% of the rated capacity, associated with problems during operation.

(e) Membrane life indicated by various firms for RO plants varied from 1 to 3 years. A membrane life of upto 5 years is claimed for ED. These claims, however, need validation as all plants evaluated operated on an average for 5-8 hours/day only and the frequency of membrane changes was higher.

(f) Pressure pumps maintenance pose several problems during operation; non-availability of spare parts at site can seriously affect their maintenance.

(g) Due to frequent deposition of salts on membrane that needed acid-wash more frequently, the maintenance of ED plants became more difficult.

(h) Scaling is a potential problem and large quantities of acid are used to prevent its formation. General practice has been to use the Langelier saturation Index of the

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concentrate to calculate acid requirements. Stiff and Davis Stability Index is recommended which results in a significant reduction in acid use.

(i) Energy costs are typically 40-60% of the total operating costs of Reverse Osmosis. The production of 1 m^3 of water requires 4-6 kWh of energy, compared with 12-18 Kwh for distillation process. However, the requirement can be reduced if energy recovery turbines are used, wherever feasible.

(j) Membrane replacements, during the life of an RO plant, are typically estimated to account for 25-35% of the operating costs. There is plenty of scope for reducing the frequency of membrane replacements.

There is no one 'best' method of desalination. Generally, Distillation and Reverse Osmosis are recommended for seawater desalination, while Reverse Osmosis and Electrodialysis are used for brackish water desalination. However, the selection and use of these processes should be very site specific, they must be selected very carefully, especially in rural areas.

One of the major considerations in the selection of a desalination process should be its cost and maintenance. However, despite the substantial costs involved, the availability of desalinated water in arid-zones can be a boon to that area. Where the water is salty, alternative water for consumption is often transported over long distances by truck or animal. When the water is sold, its unit price often exceeds that of desalinated water. Therefore, the economic conditions to support desalination already exit in many water-short areas.

9.9 CORROSION

Corrosion is the phenomenon of the interaction of a material with the environment (water, soil or air) resulting in its deterioration. In water supply corrosion causes significant loss in the hydraulic carrying capacity of pipes and fittings, poor quality of water transported and possible structural failures. Corrosion of metal due to soil electrolyte and stray currents are termed as 'underground corrosion' while that due to water flowing or contained in the pipes or containers is denoted as 'internal corrosion' or underwater corrosion .

9.9.1 MECHANISM OF CORROSION

When a metal is in contact with an electrolyte it has a tendency to ionize and go into solution. The driving force for this process is called the solution potential.

$$M + H^+ \rightleftharpoons M^+ + H \qquad (1)$$

The hydrogen ion required for this reaction comes from the ionization of water.

$$H_2O \rightleftharpoons H^+ + OH^- \qquad (2)$$

The hydrogen ion liberated on the metal surface has to be taken away for the ionization to continue according to equation (1). Otherwise, it will cover the metal surface preventing further reaction. The hydrogen atoms can be removed according to the following reactions.

$$2H + O \longrightarrow H_2O \qquad (3)$$

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$$2H \longrightarrow H_2 \qquad (4)$$

Reaction (3) is quite significant in water supplies since dissolved oxygen is always present. Reaction (4) requires low pH or a second metal which can serve as an outlet for the hydrogen (depolarizes). In water supplies such low pH conditions are not possible. Where contact with another metal is available galvanic corrosion occurs.

9.9.2 Types of Corrosion

The major types of corrosion are galvanic, concentration cell, stress, stray current electrolysis and bacteria (biochemical).

9.9.2.1 Galvanic Corrosion

When a metal is kept in an electrolyte, it forms a half cell or electrode and the potential associated with it is called half cell potential or electrode potential. In a galvanic cell anodic metal goes into solution while metal is deposited on the cathode. The metal that is placed higher in the galvanic series (electrode potential) will form anode and will be corroded. The Galvanic Series of metals and alloys given as under;

GALVANIC SERIES

Least noble Most Corroded	*Corroded End*
↑	Magnesium Magnesium alloys Zinc Aluminium 2S Cadmium Aluminium 17ST Steel or iron Cast iron Chromium iron (active Stainless type 410) Nickel-Resist cast iron 18-8 Chromium-nickel iron (active) Stainless type 304
Decrease in nobility ↑	18-8-3 chromium-nickel molybdenum-iron (active) Stainless type 316 Lead-tin solders Lead Tin Nickel (active) Inconel nickel-chromium (active)

	Hastelloy alloy C (active) Brass
Zero ↓ Increase in nobility ↓ Most noble, Least Corroded	Hydrogen Copper Bronze Copper-nickel alloys Monel nickel-copper alloy Silver solder Nickel (passive) Inconel nickel-chromium alloy (passive) Chromium-iron (passive) Stainless type 410 Titanium 18-8 Chromium-nickel-molybdenum iron Hastelloy alloy C (passive) Silver Graphite Gold Platinum *Protected End*

Galvanized iron (zinc-coated) is more serviceable than steel alone, because the iron exposed at joints is protected at the expense of the zinc.

9.9.2.2 Concentration Cell Corrosion

This type of corrosion is most prevalent and occurs when there are differences in the metal ion concentration, anion concentration, hydrogen ion concentration, temperature, or dissolved oxygen level which cause a difference in the solution potential of the same metal thereby promoting corrosion.

In water containing dissolved oxygen, the oxidation of iron from ferrous to ferric state with subsequent hydrolysis results in the increase of hydrogen ion concentration. The increase in the hydrogen ion concentration in contact with hydrogen results in a hydrogen ion concentration cell at this point thus accelerating the rate of corrosion. Similarly an oxygen concentration cell is established due to the difference in the dissolved oxygen content near the anode and cathode areas. This also increases the rate of corrosion at the anode where there is little or no oxygen. In the case of buried pipes, the nature of the soil plays an important role in the availability of oxygen. For example, lime and sandy soils have different

permeability for air penetration to the surface of the buried pipelines and local cells form between various parts of the pipeline.

The porous ferric hydroxide deposit acts as a protective coating and retards the corrosion. The accumulation of hydroxide ions near the cathode which reduces the free movement of electrons also retards the corrosion reaction.

9.9.2.3 Stray Current Corrosion

Stray current corrosion is a complex process of metal disintegration under the combined action of soil and stray currents whose usual source is electrified railway track and earthing of electrical fittings. The flow of stray current depends on the distribution of potentials in the track circuit. All metals have greater conductivity than the surrounding environment and hence the current will stay with the metal until there is discontinuity of the metal conductor. Excess of electrons will leave the metal at the points where the environment is highly conductive receptor for the current. Corrosion takes place at the anode, the points where the current leaves the metal and returns to the power source.

Of paramount importance is the simple, reliable and efficient method of measuring the densities of leakage current flowing off the metal in underground pipelines which lie in the field of action of stray currents. This stray current corrosion can be alleviated by making the interfacial resistance of the pipe significantly higher than the surrounding soil, e.g. coating of the pipe. In addition, cathodic protection can be given.

9.9.2.4 Stress Corrosion

Potential difference between different parts of the same metal is due to various factors such as non-homogeneity of surface and non-uniformity of pressure. A smooth surface is less susceptible to corrosion than a rough surface. In fact, the grain size of a metal is important since the solubility of very small grains is greater and hence it is likely to be corroded easily. Metal under stress is easily corroded because the stressed areas become anodic. Therefore, metals exposed to different stresses and strain like points of bolts and nuts in pipe supports are more corroded compared to plain pipes. When a freshly forged metal is used in machinery along with parts made of the same metal but which has been in service for sometime and in which the strain has been relaxed, more rapid corrosion of the new piece of metal is noticed. Residual stress may be relieved by annealing the metal at suitable temperature. Cycles of alternate stresses and strains which induce fatigue also tend to increase the rate of corrosion.

9.9.2.5 Bacterial (Biochemical) Corrosion

Several bacteria like the sulphate reducing bacteria, iron fixing bacteria and other micro-organisms that enter into electrolytic or ionic reactions are responsible for bacterial corrosion. Stagnation of water as in the dead ends gives scope for the development of anaerobic conditions with the production of sulphide from sulphate present in the water. The sulphide thus formed will attack the pipe metal forming black deposits of the metal sulphides which are noticed when the dead ends are flushed. Iron bacteria like Erenothrix and Leptothrix grow utilizing the energy available in the oxidation of metallic iron to the

oxide thus corroding the metal. The characteristic stingy masses that come out of handpump tubewells are the result of such growths.

9.9.3 Physical and Chemical Factors of Water Affecting Corrosion

Velocity and temperature of water in pipes affect the rate of corrosion. For aggressive waters, high velocities more than 1 mps are conducive for rapid corrosion. With adequate inhibitor concentration referred to in 9.9.6.3 (b) (1), higher velocities normally prevent metal corrosion. At low velocities the protective properties of water containing inhibitors are not utilized to their best advantage, since the slow movement does not aid the effective diffusion of the protective ingredients to the metal surface. For example at velocities below 0.6 mps corrosion is significant even in the presence of inhibitors.

In general corrosion increases with temperature. This is due to the increase of polarization and diffusion as temperature increases. Even a passive metal may become highly active at elevated temperature. If the heating products have chloride, at high temperature it may form HCl and consequently produce more corrosion. The chloride ion of alkali and alkali earth metals enhance the corrosion of many metals since the chloride ion destroys the passive film on the metals. Some anions like silicate form an insoluble product that gets deposited on the metal as a protective layer, thus acting as inhibitor of corrosion. The nature of cations present will also influence the corrosion rate. Traces of copper and other noble metals will accelerate the rate of corrosion of iron pipes. Iron and several other metals corrode more readily in ammonium salt solutions than in sodium salt solutions of the same concentration. Some inhibitors which protect iron increase the corrosion of zinc, copper and nickel because of the formation of complex cations with the metals.

Concrete constructions will be attacked by salts present in the ground water. Formation of calcium sulphate from sulphate and calcium carbonate from the concrete is responsible for the latter's corrosion. Water with 200 to 600 mg/l of sulphate and 100 to 300 mg/l of magnesium is considered to be slightly aggressive and water with 600 to 2500 mg/ l of sulphate and 300 to 1500 mg/l of magnesium are aggressive to concrete.

9.9.4 Soil Nature and Corrosion

The corrosion current will depend on the conductance of the medium which is an important factor in the corrosion of buried pipelines and structures. Dry sandy soil has low conductance but in moist clay and mineral areas it is too high. This difference in the conductivity of the soil permits its classification into cathodic and anodic sections. Stray currents from power leaks will be more dangerous to metal structures in soil. Sea water has high conductance which is a significant factor in its corrosive nature. Therefore, investigations for conductivity should form an essential part of the soil analysis particularly for large and lengthy buried pipelines apart from the routine tests of pH, redox potential, chemical analysis for calcium carbonate, sulphate, sulphide, pyrites, free carbon, moisture content, organic content and grain size analysis.

9.9.5 Corrosion Testing

Corrosion rates are often expressed as loss in weight from clean metal per unit surface area (g/cm^2) during a specified period of time (hour, day, month or year). If pits are caused by the corrosion, then the intensity of corrosion is expressed as the depth of the pit during a specified period (mm/year).

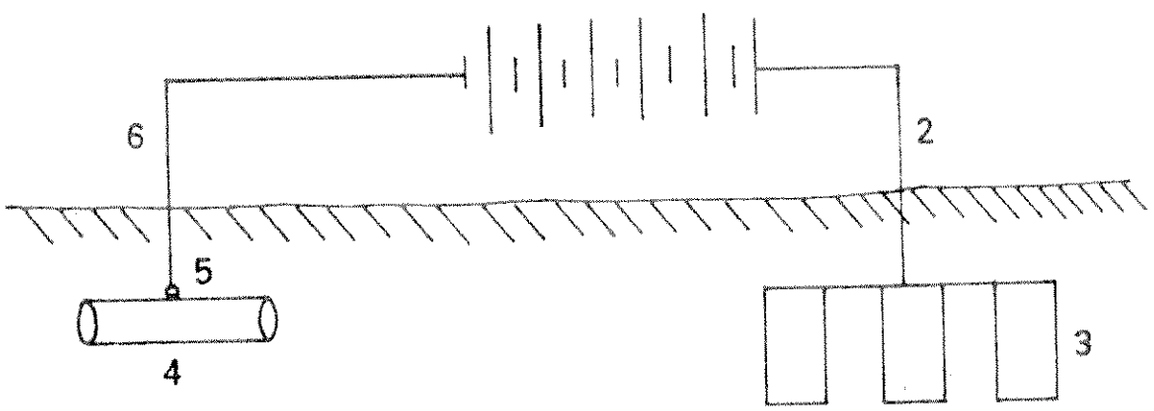

FIGURE 9.7: CATHODIC PROTECTION ASSEMBLY

Corrosion testing can be carried out either in the field or in the laboratory under controlled environment simulating field conditions. Corrosion testing is done using coupons or resistance probes. Coupons are made up of the same material as the structure and normally insulated from the main structure. The coupons are cleaned before and after insertion and the weight loss is expressed as $g/cm^2/year$ which is the measure of corrosion rate. Resistance probes are metallic rods or plates inserted at elbows using a tee in the mainstream of water or in a bypass. They operate on the principle that when a thin wire or foil corrodes its electrical resistance increases due to the decrease of its cross sectional area. The resistance measurements are converted to corrosion rate. Other field tests use thickness detectors for measuring the metal remaining in the corroded pipes or visual examination as a crude method. All these tests are not completely satisfactory by themselves.

Investigation of groundwater level and characteristics of water along with the results of laboratory or field test can be used to predict the possible corrosivity of the soil in which pipes are laid. Correlation between the soil resistivity or conductivity and corrosion is given in Table 9.7.

TABLE 9.7

CORRELATION BETWEEN THE RESISTIVITY AND CORROSION

Resistivity (ohms/cm)	Corrosion
Upto 500	Very strong
500-1500	Strong
1500-2500	Moderate
above 3000	Feeble or none

Mud, muck, clay, tidal marsh and organic soils in high water tables fall under the category of strong to very strongly corrosive. Sands, sandy loam, porous and clay loam in low water

tables are moderately corrosive. Even soils with good or feeble corrosion may contain pockets of low resistivity. It is at the junction of such soils that corrosion is seen maximum. A pipeline passing from a high resistance soil to a low resistance soil will corrode in the latter because of difference in pipe to soil potentials of the two area. The current flows from the pipe through the bad soil to the good soil and then back to the pipe.

9.9.6 CORROSION CONTROL

9.9.6.1 Cathodic Protection

Cathodic protection is the application of electricity from an external power supply or the use of galvanic methods for combating electrochemical corrosion. Cathodic protection should be used as a supplement and not as an alternative technique to other methods of protection. It may be a more suitable and expeditious method for control of external corrosion of pipelines.

(a) Basic Principle

The basic principle is to make the entire surface of the equipment cathodic thus affording protection since corrosion takes place only at the anodic surface. This can be achieved by connecting it to a D.C. source. In this case, the anode consists of specially earthed electrodes. The general arrangement in a cathodic protection assembly is shown in the Fig. 9.7.

The current from the positive pole of the D.C. source flows through the conductor 2 into the earthed anode 3 and then into the soil. From the soil the current flows to the surface of the pipe 4 to be protected and flows along the pipe to the drainage junction point 5, the conductor 6 and back to the negative terminal of the current source. Thus the entire surface of the underground pipe or equipment becomes cathodic and is protected from corrosion while the earthed anode gets corroded. The anode is usually a scrap metal e.g. old tubes, rails etc. Other metals which are resistant to attack by surrounding soil like special alloys or graphite are also used. The conductivity of the protective coating has a direct influence on the length of the protected section of the pipe. The required power increased with increasing conductivity of the coating.

(b) Preliminary Investigations

The existing pipeline has to be inspected to ascertain the sections which require protection. Other basic information required are :

(1) Plan and details of the pipelines (showing branch connections, diameter, length and wall thickness) and

(2) Location plan of the section to be protected along with :

  (i) Data on soil resistance along the section to be protected at the intervals of at least 100 m as well as the earthing points.

  (ii) Information on the availability of sources of electricity, amperage, voltage, AC/DC (phase) in the vicinity and spaces for housing current supply and controls.

(iii) Data on the conductivity or resistivity of the existing protective insulation; and

(iv) Condition of the pipeline, if it is already in use.

(c) Power Requirements

With the above data, minimum current density and maximum protection potential can be worked out. The capacity of the current source for a cathodic protection system depends on (1) length of the section to be protected (2) type and state of the coating of the pipeline (3) diameter of the pipe (4) wall thickness of the pipe (5) conductivity of the soil and (6) design of anode earthing. The power requirements vary from 0.4 to 10 kilowatts in most cases. The possible current sources are DC generator, converter-rectifier, storage batteries of dry or acid type. The pipeline should be at least 0.3 V negative to the soil.

(d) Anodes

The main power loss occurs in the anode earthing. The earthing can be carried out by any metal (pure or scrap) of any shape and also carbon forms like coke or graphite. When tubes are used the earthing can be either horizontal or vertical. Near the earthing zone, soil treatment can be done to reduce soil resistance by adding salts like sodium chloride, calcium chloride or moistening the soil, the former being better and long lasting. Carbon or graphite electrodes have longer durability than metal electrodes.

(e) Other Facilities

A cathodic protection station should provide space for housing the equipment, installation of current sources, supply and distribution zones, equipment for check measurements, construction of earthing structures and facilities for carrying out operational tests.

9.6.6.2 Protection by Sacrificial Anode

Sacrificial anodes serve the same purpose as the cathodic protection system but does not require electric power supply. The required current is supplied by an artificial galvanic couple in which the parts to be protected, usually iron or steel, is made as the cathode by choosing the other metal, having the higher galvanic potential, as the anode. Zinc, aluminium and magnesium (with sufficient purity) or their alloys which are higher up in the galvanic series must be used for this purpose. Sheets of zinc suspended in a coagulation basin is an example. A single protector anode will not be sufficient and it will be necessary to install a number of such anodes generally spaced at 4 to 6 m in the pipeline or the structure to be protected.

The performance and service life of anodes depend mostly on the nature of soil or water surrounding them. Use of fill materials in the soil such as clay and gypsum powder results in low resistance of anode earthing and yields a high current. The costs of protection by galvanic anode would be preciously higher in the case of pipeline networks in big towns since it would be necessary to suppress incidental contacts. For the application of galvanic protection the resistance of the soil should be less than 12 ohm-m. A higher resistance of the

circuit can neither achieve the required current density nor reduction of the pipe to soil potential. In such cases, cathodic protection by means of external power supply offers better protection.

9.9.6.3 Control Of Internal Corrosion

(a) Associated Factors

Corrosion of the interior surfaces of waterpipes results in reduced carrying capacity, redwater and taste and odour problems. Experience in the country has shown that the 'C' value of cast iron pipes have gone down to as low as 45 in 30 years of service due to corrosion.

The mineral content, dissolved oxygen level and pH of water influence the corrosion rate of mild steel. The effect of dissolved oxygen is decreased by increase in pH. With no minerals the pH of water in mild steel containers adjusts itself to about 8.4 and corrosion becomes negligible. Pitting can occur at joints and welds (stressed areas) if pH is around 8.4 but not above that required for complete protection.

In the absence of carbonate minerals, increasing concentration of other minerals such as chloride and sulphate salts increases the corrosion rate at all pH values below the pitting range of pH. Increasing temperature accelerates both general corrosion and pitting.

Bicarbonates inhibit corrosion. In the absence of calcium, the inhibitory effect of bicarbonate is maximum at pH 6.5 to 7.0 when its concentrations are 5 to 10 times above the chlorides and sulphates. It is minimum at pH 8 to 9.

When dissolved oxygen is absent, the type of minerals present have insignificant effect on mild steel.

The method of controlling corrosion by deposition of calcium carbonate was first suggested by Langelier. According to him the tendency of deposition of calcium carbonate depends upon carbon dioxide and calcium carbonate balance in water.

Langelier index, I = pH - pHs, where pHs is associated with calcium carbonate equilibrium (determined by marble test or by calculation from dissolved solids) and pH is the actual pH of the water in the pipeline. When I = 0 neither deposition nor dissolution of calcium carbonate takes place. A positive value indicates that the water is oversaturated with calcium carbonate (or lacking in free carbon dioxide) and will tend to deposit calcium carbonate. A negative value indicates that the water is undersaturated (or has an excess of free carbon dioxide) and will tend to dissolve existing deposits of calcium carbonate,

The Langelier's saturation index is not quantitative but shows only the directional tendency. Hence other indices of evaluating the scale-forming or dissolving properties of water have been developed.

An index was proposed by Ryznar, using the empirical expression 2 pHs-pH, which is known as Ryznar Stability Index to differentiate it from the saturation index. Values of the stability index greater than about 7.0 indicate a corrosive water, while, values less than 7.0 indicate a scale forming water. This index is of particular interest in evaluating waters of widely different composition.

A minimum alkalinity of 50 to 100 mg/l as $CaCO_3$ and a minimum of about 50 mg/l calcium (as $CaCO_3$) must be present at normal temperature (0° to 70°C) for giving some degree of protection. The protective action is decreased by increasing proportions of chlorides and sulphates. This limitation is less significant in the absence of dissolved oxygen.

Excessive residual chlorine may increase the corrosiveness of water. High temperatures will tend to increase the rate of corrosion while other factors remaining constant. Soft waters are generally more corrosive than hard waters.

Carbon dioxide acidity or mineral acidity will increase corrosion of iron or destroy the protective coatings. High pH will decrease corrosion, but very high pH levels may be destructive to galvanized or other protective coatings thereby actually increasing the corrosion.

(b) Inhibitors

An inhibitor is a chemical which when added to the corrosive environment will effectively decrease the corrosion rate. It can be considered as the opposite of a catalyst. It retards or stops the corrosion reaction. Inhibitors may be organic or inorganic in nature. Most of the inorganic inhibitors such as silicate, chromate, phosphate, borate etc. control the rate of corrosion by acting on the anode. The use of some of these is not advisable under all conditions. For example the improper use of chromate may accelerate the rate of corrosion rather than inhibiting. If hydrogen polarization is present, the addition of chromate or any other oxidizing agent will cause depolarization and thus increase the flow of corrosion current. Again if insufficient amount of inhibitor is used to provide a complete film over the anode, the small area left exposed will corrode with increased rapidity thereby causing pitting. Sodium silicate is used as a good inhibitor. Alkaline sodium nitrate alone or in conjunction with other inorganic inhibitors such as phosphate is good inhibitor. Sodium benzoate with sodium nitrate is a good inhibitor for iron.

Organic inhibitors may act in a variety of ways. Organic colloids form protective layers by adsorption. Organic bases form positive ions containing hydrophobic groups. These positive cations attach themselves through nitrogen to the cathodic surface. Their effectiveness as inhibitors depend on the size of the hydrocarbon. A few parts per million of tertiary amine gives almost complete protection. High molecular weight amines derived from rosin are good inhibitors. The protective action of the inhibitors increase with temperature.

Vapour phase inhibitors (VPI) vaporize readily and form an inhibiting (or) protective layer. These inhibitors are used to protect steel or iron in presence of moisture and SO_2 Metal parts may be wrapped in papers impregnated with VPI instead of using layers of grease or oil as rust protective substances. Dicyclohexyl ammonium nitrate and chlorohexyl amine carbonate are used as good VPI.

Some of these inhibitors may not be suitable for community water supply unless they are proved to be harmless for consumption. But they are suitable for industrial water systems.

(c) Methods

(i) Deposition of Protective Coatings

A thin film of calcium carbonate can be deposited by the water on the inner surface of pipes by adjusting pH and alkalinity of the water to keep the Langelier Saturation Index 'I' to a slightly positive value. Lime or soda ash or both can be used to raise pH and alkalinity.

Small amount of sodium silicate can deposit dense, adherent but slightly permeable film. A dose of 12 to 16 mg/l is maintained in the beginning and gradually reduced to 3 to 4 mg/l. Organic coatings such as enamels, tar or bituminous coating are effective only to the extent of their coverage and durability. Epoxy coatings hold promise but their toxic effects due to leaching are not fully established. For cast iron and steel pipes, cement lining of the interior surface is satisfactory. Insertion of plastic pipe into an existing partly corroded pipe is also useful. For controlling corrosion of reinforcing steel and preventing disintegration of concrete in RC dome covers of overhead tanks, the concrete cover of such domes may be adequately protected (IS No. 456 : 1978). Protective coating to reinforcement is also suggested.

Some polyphosphates are reported to inhibit corrosion by forming protective films on the cathodic area. They also function as inhibitors for precipitation of calcium, magnesium and iron. Red water problem has been minimized in certain cases because oxidation and precipitation of iron is prevented. Sodium hexametaphosphate (Calgon) is the most widely used polyphosphate. The effectiveness of polyphosphates is progressively greater at increasing turbulent velocities and at increasing concentrations. The initial dose may be as high as to 6 to 12 mg/l and then reduced to 1 to 2 mg/l. This can prevent the formation of rough deposits and remove sharp projections from the existing rough films.

(ii) Treatment of Water

Treatment of water such as adjustment of pH, removal of carbon dioxide, increase in calcium or carbonate ion concentration or addition of inhibitors can overcome to a large extent the corrosive nature of water. Chemical treatment can be effective as only a supplement to other methods like protective coatings and is limited by the cost.

Iron bacteria problems in tubewells can be overcome by treating the well with concentrated bleaching powder solution dose of 50 mg/l (as chlorine) and a contact period of 6 hours. It is necessary to periodically flush out the dead ends so that stagnation for more than a month does not take place. After flushing, these dead ends have to be disinfected by chlorine. De-oxygenation or deactivation of water is the essence of reducing corrosive nature of water and is accomplished by passing over heated scraps of iron or by deoxygenation under vacuum. These methods, however, are not practised in community water supply systems because of cost considerations but are eminently suitable for industrial water systems.

CHAPTER 10
DISTRIBUTION SYSTEM

10.1 GENERAL

The purpose of the distribution system is to convey wholesome water to the consumer at adequate residual pressure in sufficient quantity at convenient points. Water distribution usually accounts for 40 to 70% of the capital cost of the water supply project. As such, proper design and layout of the system is of great importance. Metering is recommended for all cities as indicated in section 17.4.2.

10.2 BASIC REQUIREMENTS

The requirements for the distribution system may be classified as functional and hydraulic. The geometrical configuration of pipes, reservoirs and boosters, selection and proper location of valves, specials, etc., for efficient operation and maintenance and overall economy in cost constitute some of the functional aspects. Adequate residual pressure at the maximum demand depends upon the hydraulic characteristics of the system.

10.2.1 CONTINUOUS VERSUS INTERMITTENT SYSTEM OF SUPPLY

In the continuous system of supply, water is made available to consumer all the twenty-four hours a day, whereas in the intermittent system, the consumer gets supply only for certain fixed hours (a few hours in the morning and a few hours in the evening).

The intermittent system suffers from several disadvantages. The distribution system is usually designed as a continuous system but often operated as an intermittent one. There is always a constant doubt about the supply in the minds of the consumers. This leads to limited use of water supplied, which does not promote personal hygiene. The water is stored during non-supply hours in all sorts of vessels which might contaminate it and once the supply is resumed, this water is wasted and fresh supply stored. During non-supply hours, polluted water might reach the water mains through leaky joints and thus could pollute the protected water. There will be difficulty in finding sufficient water for fire fighting purposes also during these hours. The taps are always kept open in such system leading to wastage when supply is resumed. This system does not promote hygiene and hence, wherever possible, intermittent supply should be discouraged.

10.2.2 SYSTEM PATTERN

For efficient and equitable distribution of water, a grid pattern, where the different mains are interconnected keeping dead ends to a minimum, is recommended. The system facilitates

any one point being fed at least from two different directions. For small water supplies, the tree or branch system with smaller mains branching off from a single trunk main may be adequate.

10.2.3 Zoning

Zoning in the distribution system ensures equalization of supply of water throughout the area. The zoning depends upon (a) density of population (b) type of locality (c) topography and (d) facility for isolating for assessment of waste and leak detection. If there is an average elevation difference of 15 to 25m between zones, then each zone should be served by a separate system. The neighboring zones may be interconnected to provide emergency supplies. The valves between the zones, however, should normally be kept closed and not partially opened. The layout should be such that the difference in pressure between different areas of the same zone or same system does not exceed 3 to 5m.

10.2.4 System of Supply

In selecting a source of water supply for a town, the mode of conveyance of water from the source to the town is a factor for consideration. Water could be conveyed by gravity alone, or by pumping, or by gravity-cum-pumping. Any of these three modes could be selected based mainly on the elevation of the source of supply with respect to the town. Efforts should be made to minimize the cost of transmission by considering the various alternatives and their suitability for the given situation.

10.2.5 Location of Service Reservoirs

The location of service reservoirs is of importance for regulation of pressures in the distribution system as well as for coping up with fluctuating demands. In a distribution system fed by a single reservoir, the ideal location is a central place in the distribution system, which effects maximum economy on pipe sizes. Where the system is fed by direct pumping as well as through reservoirs, the location of the reservoirs may be at the tail end of the system. If topography permits, ground level reservoirs may be located taking full advantage of differences in elevation. Even when the system is fed by a central reservoir, it may be desirable to have tail end reservoirs for the more distant districts. These tail end reservoirs may be fed by direct supply during lean hours or booster facilities may be provided.

10.3 GENERAL DESIGN GUIDE LINES

10.3.1 Peak Factor

The per capita rate of water supply indicates only the average consumption of water per day per person over a period of one year. In the design of water supply distribution system, it is to be recognized that consumption varies with the season, month, day and hour. As far as the design of distribution system is concerned, it is the hourly variation in consumption that matters. The fluctuation in consumption is accounted for, by considering the peak rate of consumption (which is equal to average rate multiplied by a peak factor) as rate of flow in the design of distribution system.

The variation in the demand will be more pronounced in the case of smaller population and will gradually even out with the increase in population. This is so because in a large population different habits and customs of several groups tend to minimize the variation in the demand pattern.

The following peak factors are recommended for various population figures:

For population less than 50,000	3.0
For a population range of 50,000 to 2,00,000	2.5
For population above 2,00,000	2.0
For Small Water Supply Schemes (Where supply is effected through standposts for only 6 hours)	3.0

10.3.2 Fire Demand

Fire demand can be assessed as per the norms given in section 2.2.8.3. Reference can also be made to IS 9668-1980

10.3.3 Residual Pressure

Distribution system should be designed for the following minimum residual pressures at ferrule points:

Single storey building ⇒ 7 m

Two storey building ⇒ 12 m

Three storey building ⇒ 17m

Distribution system should not ordinarily be designed for residual pressures exceeding 22 meters. Multistoreyed buildings needing higher pressure should be provided with boosters.

10.3.4 Minimum Pipe Sizes

Minimum Pipe sizes of 100 mm for towns having population upto 50,000 and 150 mm for those above 50,000 are recommended. For dead ends, less than 100 mm can be considered. If it is a grid, less than 100 mm can be used in situations where no further expansion is contemplated.

10.3.5 Layout

The distribution layout should be such as to facilitate hydraulic isolation of sections, metering for assessment and control of leakage and wastage.

10.3.6 Elevation of Reservoir

The elevation of the service reservoir should be such as to maintain the minimum residual pressure in the distribution system consistent with its cost effectiveness. The hydraulic gradient in the pipe should normally be between 1 and 4 per thousand at peak flow.

A suitable combination of pipe sizes and staging height has to be determined for optimization of the system. The staging height of service reservoirs is normally kept as 15-20m.

10.3.7 Boosting

For distant localities, boosters may be provided instead of increasing the size of mains or height of the reservoir unduly for maintaining the required pressure.

10.3.8 Location of Mains

For roads wider than 25 meters, the distribution pipes should be provided on both sides of the road, by running rider mains suitably linked with trunk mains.

10.3.9 Valves

(a) Sluice Valves

Sluice valves shall be located on at least three sides of every cross-junction and at every kilometre on long mains. The size of the sluice valve shall be the same as the size of the main up to 300 mm diameter and at least two-thirds the size of main for larger diameters.

(b) Air Valves

These have been discussed in 6.16.3.

(c) Scour or Blow Off Valves

The scour or blow off valves have been discussed in 6.16.2.

(d) Flow Dividing Valves

These specially devised and constructed valves are used in distribution and other mains at the branch point to ensure that the assigned flow in a distribution main is always maintained. These are based on the principle that the diaphragm or the other arrangement in valves opens proportionally depending upon the upstream pressure allowing the regulation of flow, irrespective of the pressure conditions obtained in the distribution main.

(e) Maximum Demand Controllers

The maximum demand controller permits all flows upto a preset value and automatically assumes control when the flow just exceeds this predetermined rate, thus preventing excess withdrawals. This form of controller finds considerable use both in municipal and industrial installations, where two or more users taking water from a common source, are to be prevented from consuming more than a set quantity.

10.4 SERVICE RESERVOIRS

10.4.1 Function

The service reservoirs provide a suitable reserve of treated water with minimum interruptions of supply due to failure of mains, pumps etc. They also enable meeting the widely fluctuating demands when the supply is by intermittent pumping. They are also helpful in reducing the size of the mains which would otherwise be necessary to meet the

peak rates of demand. They can serve as an alternative to partial duplication of an existing feeder main as the load on the main increases.

10.4.2 Capacity

The capacity of the service reservoir to be provided depends upon the better economic alternatives amongst various options. A system supplied by pumps with 100% standby will require less storage capacity than that with less standby provision. Similarly a system divided into interconnected zones will require less storage capacity for all the zones except for the zones at higher elevations.

However, the minimum service or balancing capacity depends on the hours and rate of pumping in a day, the probable variation of demand or consumption over a day, the hours of supply can be calculated from a mass diagram or by a demand and pumping budget. The variation of demand in a day for a town which depends on the supply hours may have to be assumed or known from similar towns or determined based on household survey.

Typical example on estimation of storage capacity is given in Appendix 10.1.

10.4.3 Structure

The ground level reservoir is generally preferred as storage reservoir which is circular or square or rectangular in shape. If it is circular, it is usually constructed of RCC and in the case of other shapes it is constructed either of RCC or masonry. The elevated reservoirs are used principally as distributing reservoirs and can have shapes like circular, square, rectangular and conical or may be of Intze type. They are generally made of RCC or prestressed concrete. Small capacity tanks can be fabricated with steel or PVC or HDPE. Circular shapes are generally preferable as the length of the wall for a given capacity is a minimum and further the wall itself is self-supporting and does not require counterfort. Reservoirs of one compartment are generally square and those of two or three compartments may be rectangular with length equal to one and half times the breadth. The economical water depth for reservoirs with flat bottom upto $1000m^3$ capacity is between 3 and 5.5m. The service reservoirs should be covered to avoid contamination and prevent algal growths. Suitable provision should be made for manholes, mosquito-proof ventilation, access ladders, scour and overflow arrangements, water level indicator, and if found necessary, lightning arresters.

10.4.4 Inlets and Outlets

The draw pipe should be placed 15 centimenters above the floor and is usually provided with a strainer of perforated cast iron. The reservoirs filled by gravity are provided with ball valves of the equilibrium or other type which close when water reaches full tank level. The overflow and scour main should be of sufficient size to take away by gravity the maximum flow that can be delivered through the reservoir. The outlet of the scour and overflow mains should be protected against the entry of vermin and from other sources of contamination. The inlet or outlet of reservoir should be such that no water stagnates. When there are two or more compartments, each compartment should have separate inlet and outlet arrangements, while the scour and overflow from each compartment may be connected to a

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single line. To avoid waste of energy, it is advantageous to form the opening of the outlet with a configuration identical to the surface. This could be achieved by providing a bell mouth at the opening of the outlet pipe. The details of the bell mouth for different sizes of openings are given in Appendix 10.2.

10.5 BALANCING RESERVOIRS

The tank is said to be "floating on the line" when connected by a single pipe to the source and the distribution system. When the rate of supply exceeds the demand, water flows into the tank. When demand exceeds supply, water flows through the same pipe from the tank. The relation between rate of supply, rate of demand and tank capacity is based on a study of the service required as in case of service reservoirs.

When the balancing tank floating on the line is designed for the full service storage based on a study of the hydrograph of demand, its location and altitude is governed by the same conditions as are applicable to the service reservoir. Where the distribution system is designed for direct pumping into the system, it is advantageous to provide a balancing tank at the end of the system with a nominal capacity (1 or 2 hours) to provide pressure relief and improve the tail end distribution. The balancing reservoir has the advantage of minimum of pipe work and operational maintenance.

10.6 HYDRAULIC NETWORK ANALYSIS

10.6.1 PRINCIPLES

Hydraulic analysis of the pipe network is the building block for the design of water distribution system and essentially involves determination of flow conditions associated with specified pipe sizes, the location and size of reservoir and capacity of pumps.

Irrespective of the methods used, the hydraulic analysis of pipe network is based on fundamental laws, viz., $\sum Q = 0$ at a junction, $\sum H = 0$ around a loop or a circuit and $h = kQ^n$, which is the exponential friction flow equation relating the head loss to the flow in pipe.

The problem of hydraulic network balancing is one of finding either the distribution of flows in the pipes given a set of nodal inflows and outflows, or the distribution of pipe head losses given a set of some nodal water elevations, subject to Kirchoff's laws. From the layout, a proper skeletonizing of the network is done and pipe lengths are determined. On the basis of pipe sizes chosen by the engineer from experience the network balancing reduces to a problem of solving a set of non-linear simultaneous equations in the pipe flows and pipe head losses. Either of the two methods, viz.;

(a) Balancing head losses around loops by correcting assumed flows, or

(b) Balancing flows at junctions by correcting assumed head losses in pipes,

is applicable. Notable among the several methods applicable are those developed by (i) Hardy Cross, (ii) the electrical analogy method developed by McIlroy (iii) the graph theory approach and more recently, (iv) iterative procedures such as Newton-Raphson method using digital computers. The second method belongs to analog category and the rest belong

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