

COOLING WATER– ‘PROBLEMS AND SOLUTIONS’

Course Content

PART I - COOLING WATER SYSTEMS – AN OVERVIEW

Water with some exceptional thermal and physical properties happened to be the most readily available medium, and is comparatively an economically viable coolant.

It is however reckoned that the quality of water, with regard to dissolved chemical constituents varies from source to source.

The primary cooling water sources could be any of the followings:

1. Surface Water: - Rivers, reservoirs, streams, lake or ponds.
2. Ground Water: - Shallow or deep well waters
3. Saline Water: - Sea, oceans or salty lake
4. Waste & Effluent Water: - Municipal waste, Industrial effluents, Gray water, Sewage

In General

- Surface water is fed from rain or streams. It contains considerable amount of dissolved suspended impurities.
- Lake water has more or less constant chemical analysis. It usually contains lesser amount of dissolved materials but has large quantities of organic matter.
- Spring or well water is cleaner in appearance but contains most of dissolved salts. These usually have high organic purity.
- The ground water supplies contain less suspended matter than the surface water supplies.
- Seawater is the most impure form of natural water. Seawater contains on average 3-5% of dissolved salts out of which 2.6% is NaCl.
- Because of environmental regulations of zero plant discharge, water cost and water scarcity, some plants use saline or effluents as cooling water.

Type of Cooling Systems

The salient features of three common cooling systems is described below:

1) Open Re-circulation Systems: *Cooling Towers, Spray Ponds, Fountains*

- The water is cooled as a result of evaporation, in direct contact with air.

- Water is re-circulated and reused again and again. There is considerable water loss due to evaporation and drift that is made up.
- These systems are prone to corrosion, fouling, scale and microbial contamination.

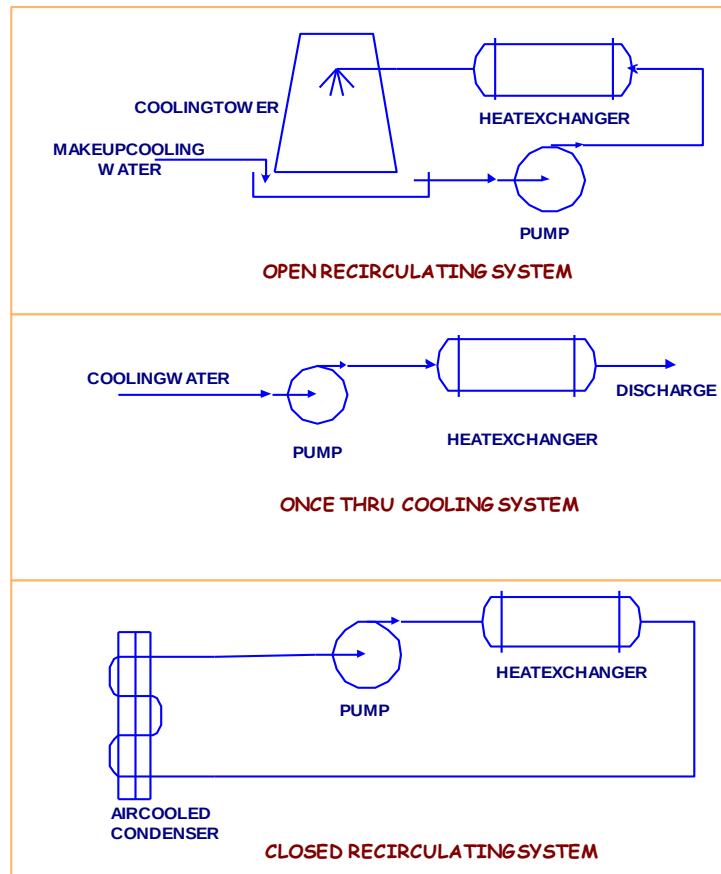
2) Once Thru Cooling Systems:

- The water is drawn from estuary, lake or river and is discharged back to the source.
- System could be utilized for capital-intensive plants, where large amount of water is needed and water is available in abundance.
- Environmental regulations of hot water discharge or concerns of aquatic life go against using this system.
- System is prone to corrosion, scaling and fouling.

3) Closed Re-circulating Systems:

- The cooling takes place through air-cooled exchangers similar to radiators.
- The water loss is negligible as the water remains in a closed loop. This system consumes very little water for make up.
- This system is recommended where water is scarce.
- These systems are prone to corrosion and fouling.

The Figure below shows the schematic representation:



The open re-circulation system is most critical from water treatment point of view. The other are important but the extent of treatment is limited as the water is either used only once in large quantities or in closed circuit the water quality is not impacted considerably due to negligible water loss.

In an open re-circulation system, the water is lost through evaporation, bleed-off, and drift. To replace the lost water and maintain its cooling function, more make-up water is added to the system.

When water is evaporated or lost from a cooling tower, the solids and chemicals used to treat the tower remain in the system and when water is intentionally "bled" from the system, the chemicals lost through bleed must be replaced for the system to remain protected.

In addition, the open water spray continuously "scrubs" airborne contaminants from the atmosphere. If these particulate are not removed from the system, it provides an excellent breeding ground for algae and bacteria.

The build up impurities and its concentration result in fouling of heat exchangers, corrosion and plugging of system due to algae formation thus adversely affecting normal productive operations.

It is therefore extremely desirable that close attention be given to these aspects to avoid damage to equipment and process efficiencies.

The contents hereunder explain the means and direction of effective treatment.

PART II - PROBLEMS OF WATER

Most sources of water contain impurities. The most common are calcium and magnesium bicarbonates/sulphates. There are various other salts and impurities in various proportions.

Bicarbonate and sulphates are the most insoluble salts. These tend to precipitate as CaCO_3 / MgCO_3 with increase of temperatures.

It is important to understand the basic water chemistry, before we proceed further.

What are the important properties of cooling water?

In general, the important properties are:

1. Conductivity: A measure of water's ability to conduct electricity in cooling water. It indicates the amount of dissolved minerals in water. Conductivity is measured in micro-mhos and can vary from a few for distilled water to over 10000 for saline water.
2. pH: A measure of acidity or basicity of water. The pH scale runs from 0 to 14 with 0 representing the maximum acidity and 14, the maximum basicity.

- **How pH does affect the system?**

Control of pH is critical for the majority of cooling water treatment programs.

In general, when pH is below recommended ranges, the chances for corrosion increase and when pH is above recommended ranges, the chances for scale formation increase. The effectiveness of many biocides also depends on pH; therefore high or low pHs may alleviate the growth of microbiological problems.

- 3) Alkalinity: In cooling water two forms of alkalinity play a key role. These are carbonate (CO_3) alkalinity and bicarbonate (HCO_3) alkalinity. Bicarbonate alkalinity is by far the most common. Alkalinity and pH are related because increase in pH indicates increases in alkalinity and vice versa.

- **How does Alkalinity affect the system?**

When water with carbonate or bicarbonate alkalinity is heated, the alkalinity is broken down to carbon dioxide. The carbon dioxide released, combines with the water to give carbonic acid, which can cause corrosion of iron or steel equipment. The corrosion products react further with alkalinity and the deposits can build up in the same manner as calcium carbonate scale.

- 4) **Hardness:** The hardness in water is the amount of alkaline-earth cations, calcium and magnesium minerals. The sum of these two is the total hardness. The hardness of natural waters can vary from a few parts per million (ppm) to over 800 ppm.

The total hardness is then broken down into two categories

- a) The carbonate or temporary hardness
- b) The non-carbonate or permanent hardness

▪ **How does Hardness affect the system?**

Hardness particularly the temporary hardness is the most common and is responsible for the deposition of calcium carbonate scale in pipes and equipment.

✓ *The other important parameters are:*

- **Total Suspended Solids:** The measure of particulate matter suspended in a sample of water or wastewater. After filtering a sample of a known volume, the filter is dried and weighed to determine the residue retained. The amount of suspended solids measured in mg/l
- **Total Dissolved Solids:** This represents all the dissolved constituents for e.g. Ca, Cl, and Na etc. It is measured in mg/l
- **Total Cations:** Represents positive ions, Na^+ , Ca^{++} etc
- **Total Anions:** Represents negative ions, SO_4^- , Cl^- , etc
- **BOD:** Signify Biological Oxygen Demand and is measured in mg/l
- **COD:** Chemical Oxygen Demand and is measured in mg/l
- **TOC:** Total Organic Carbon and is measured in mg/l
- **Total Silica** that is measured in mg/l of SiO_2
- **Turbidity:** signify suspended matter in water or wastewater that scatters or otherwise interferes with the passage of light through the water.



WATER RELATED PROBLEMS & CHEMICAL TREATMENT

The chemistry of water has a direct impact on the four main problems of cooling water systems.

1 SCALE

Water impurities such as calcium and magnesium hardness can precipitate and deposit depending on their concentrations, water temperature, pH, alkalinity, and other water characteristics. The deposit forms a film inside the surfaces, technically known as scale that in addition to its high insulating value; progressively narrows pipe internal diameters, roughens tube surfaces and thereby impeding proper flow.

While scale formation proceeds more rapidly in open re-circulating systems owing to the concentration effect of evaporation, once-through systems are not exempt from scaling if high temperatures are combined with silt and iron.

1. What is scale?

Scale is a dense coating of predominantly inorganic material formed from the precipitation of water-soluble constituents. Some common scales are

- Calcium Carbonate
- Calcium phosphate
- Magnesium salts
- Silica

2. Principle Factors Responsible for Scale Formation

- Calcium content of water
- Alkalinity or pH of water
- Temperature of re-circulation water
- Higher concentration of solids (TDS)
- Insufficient bleed off from cooling towers

3. How do these factors increase the amount of scaling?

As any of above factors changes, scaling tendencies also change. Most salts become more soluble as temperature increases. However, some salts, such as calcium carbonate, become less soluble as temperature increases. Therefore they often cause deposits at higher temperatures.

A change in pH or alkalinity can greatly affect scale formation. As alkalinity increases, calcium carbonate- the most common scale constituent in cooling systems-decreases in solubility and deposits. Some materials, such as silica (SiO_2) are less soluble at lower alkalinities.

Hardness levels are associated with the tendencies of cooling waters to be scale forming or not. Higher the level of scale forming solids, the greater the chances of scale formation

4. How can scale formation be controlled?

There are four basic means to control scale.

- Limit the concentration of scale forming materials by controlling cycles of concentration or by removing the minerals before they enter the system. A part of water is purposely drained off (blow down) to prevent minerals built up. A cycle of concentration is the ratio of the make-up rate to the blow down rate.
- Feed acid to keep the common scale forming materials dissolved form.
- Make the mechanical changes in the system to reduce the chances for scale formation. Increased water flow and exchangers with larger surface areas are examples.
- Treat with chemicals designed to prevent scale.

5. How do chemical scale inhibitors work?

- ✓ Scale inhibitor chemicals keep the scale forming materials in soluble form and do not allow deposit to form.
- ✓ Scale conditioners modify the crystal structure of scale, creating a bulky transportable sludge instead of hard deposit.

6. What are common scale-control chemicals?

- ✓ Scale inhibitors: Organic phosphates, polyphosphates, polymer compounds
- ✓ Scale conditioning compounds: Lignin, tannins, polymeric compounds

7. What are the effects of Scale Deposits?

The build up of scale leads directly to

- Loss of heat transfer efficiency
- Loss of production
- Increased downtime and maintenance costs
- High-energy costs

8. What is the most important factor in scale control?

To prevent formation of scale, water is treated prior to using it for coolant purposes.

The water treatment methods are classified in three broad categories:

- Water Treatment (Softening, Dealkalization, Demineralization, Reverse Osmosis)
- Chemical dosing

A chemical program in addition to the cooling water treatment is the only way to insure that scale formation does not become a problem.

2 CORROSION

Water tends to convert metals (such as mild steel) to their oxide states. The corrosion is a result of dissolved gases, improper pH control or formation of differential aeration cells under deposits. A localized effect of corrosion results in built up of holes; the phenomenon known as pitting. Failures of this type can be catastrophic, leading to costly downtime for repairs and equipment replacement and even total plant shutdown.

1. What is corrosion?

Corrosion is an electrochemical process by which a metal returns to its natural state i.e. forms oxide in contact with oxygen.

2. How does corrosion take place?

For corrosion to occur, a corrosion cell, consisting of an anode, a cathode and an electrolyte must exist. Metal ions dissolve into the electrolyte (water) at the anode. Electrically charged particles are left behind. These electrons flow through the metal to other points (cathodes) where electron-consuming reactions occur. The result of this activity is the loss of metal and often the formation of a deposit.

3. Which materials are susceptible to corrosion?

Mild steel is a commonly used metal in the cooling water system that is most susceptible to corrosion. Other metals in general, such as copper, stainless steel, aluminum alloys also do corrode but the process is slow. However in some waters and in presence of dissolved gases, such as H_2S or NH_3 , the corrosion to these metals is more severe & destructive than to mild steel.

4. What types of corrosion exists in cooling water systems?

Many different type of corrosion exist, but the most common is often characterized as general, localized or pitting and galvanic.

- ✓ General attack: exists when the corrosion is uniformly distributed over the metal surface. The considerable amount of iron oxide produced contributes to fouling problems.
- ✓ Pitting attack: exists when only small area of the metal corrodes. Pitting may perforate the metal in short time. The main source for pitting attack is dissolved oxygen.
- ✓ Galvanic attack: can occur when two different metals are in contact. The more active metal corrodes rapidly. Common examples in water systems are steel & brass, aluminum & steel, Zinc & steel and zinc & brass. If galvanic attack occurs, the metal named first will corrode.

5. What water characteristics affect corrosion?

- Oxygen and other dissolved gasses
- Dissolved or suspended solids
- Alkalinity or acidity (pH)
- Velocity
- Temperature
- Microbial activity

6. How does oxygen affect corrosion?

Oxygen dissolved in water is essential for the cathodic reaction to take place.

7. *How do dissolved or suspended solids affect corrosion?*

Dissolved solids can affect the corrosion reaction by increasing the electrical conductivity of the water. The higher is the dissolved solids concentration, the greater shall be the conductivity and more is the likelihood of corrosion. Dissolved chlorides and sulphates are particularly corrosive.

8. *How does alkalinity or acidity affect corrosion?*

Acidic and slightly alkaline water can dissolve metal and the protective oxide film on metal surfaces. More alkaline water favors the formation of the protective oxide layer.

9. *How does the water velocity affect corrosion?*

High velocity water increases corrosion by transporting oxygen to the metal and carrying away the products of corrosion at a faster rate. When water velocity is low, deposition of suspended solids can establish localized corrosion cells, thereby increasing corrosion rates.

10. *How does temperature affect corrosion?*

Every 25-30°F increase in temperature causes corrosion rates to double. Above 160°F, additional temperature increases have relatively little effect on corrosion rates in cooling water system.

11. *How does microbial growth affect corrosion?*

Microbial growths promote the formation of corrosion cells in addition; the byproducts of some organisms, such as hydrogen sulphide from anaerobic corrosive bacteria are corrosive.

12. *What methods are used to prevent corrosion?*

Corrosion can be prevented or minimized by one or more of the following methods:

- When designing a new system choose corrosion resistant materials to minimize the effect of the aggressive environment.
- Adjust pH.
- Apply protective coatings such as paints, metal plating, tar or plastics
- Protect cathodically, using sacrificial metals.

- Add protective film-forming chemical inhibitors that the water can distribute to all wetted parts of the system.

13. How do chemical corrosion inhibitors work?

Chemical inhibitors reduce or stop corrosion by interfering with corrosion mechanism. Inhibiting usually affect either the anode or the cathode.

- ✓ [Anodic corrosion](#) inhibitors establish a protective film on the anode. Though these inhibitors can be effective, they can be dangerous, if sufficient anodic inhibitor is present, the entire corrosion potential occurs at the unprotected anode sites. This causes severe localized (or pitting) attack.
- ✓ [Cathodic corrosion](#) inhibitors form a protective film on the cathode. These inhibitors reduce the corrosion rate in direct proportion to the reduction of cathodic area.
- ✓ [General corrosion](#) inhibitors protect by filming all metal surfaces whether anodic or cathodic.

14. What inhibitors are commonly used for cooling water systems?

- ✓ [Mainly anodic](#): Chromates, Nitrites, Orthophosphates, and Silicates
- ✓ [Mainly cathodic](#): Bicarbonates, Metal cations, Polyphosphates
- ✓ [General](#): Soluble oils, other organics

15. Does the type of cooling system affect treatment application principles?

Yes. The choice of treatment is basically a matter of economics. In a once-through system, a very large volume of water passes through the system only once. Protection can be obtained with relatively few parts per million (ppm) of treatment because the water does not change in composition significantly while passing through the equipment.

In an open re-circulation system, more chemical may be present because the water composition changes significantly through the evaporation process. Corrosive and scaling constituents are concentrated. However, treatment chemicals also concentrate by evaporation, therefore, after the initial dosages only moderate dosages will maintain the higher level of treatment needed for these systems.

In a closed re-circulation system, water composition remains fairly constant. There is very little loss of either water or treatment chemical. The best form of treatment recommendation for closed water system includes the dosage of film forming inhibitors such as nitrites and molybdate.

16. What are the effects of corrosion on the re-circulation system?

- Damage to pump seals
 - Plugged lines
 - Loss of heat transfer efficiency
 - High maintenance & replacement costs
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3

BIOLOGICAL GROWTHS

The uncontrolled multiplication of bacteria, algae, fungi and other microorganisms can lead to deposit formations, which contribute to fouling, corrosion and scale. A biological growth has been recognized as an important contributor to impaired heat transfer efficiency in cooling water systems.

1. How do microorganisms enter a cooling water system?

The make-up water supply, wind and insects can all carry microorganisms into a cooling water system.

2. What factors contribute to microbial growth?

The main factors are:

- Degree of infected microbial contamination already build up
- Nutrients: For instance, hydrocarbons or other carbon sources can serve as food for slime-forming organisms.
- Atmosphere: Organism growth depends upon the availability of oxygen or carbon dioxide.
- Location: The factors such as amount of light and moisture significantly affect growth rates.
- Temperatures: Organisms that compound into masses (slime) tend to flourish between 40 and 150 deg F.

3. How does microbial slime impact scale formation?

Slime can cause treatment chemicals for scale to be ineffective and hence promotes scale formation.

4. How microbial slime does cause fouling?

Slime masses themselves are foulants. They provide excellent sites for the deposition of other foulants. Although many organisms tend to die at high temperatures the remaining debris fouls metal surfaces. Generally microbial organisms form colonies at points of low water velocity. Heat exchangers & cooling towers are therefore subject to microbial contamination.

5. *What factors must be considered in planning an effective microbial control program?*

The most important factors are:

- Types and quantities of microbial organisms
- Microbial trouble signs such as wood rot, slime deposits and corrosion
- Operating characteristics of the system, such as temperature flow rate and water composition
- Types of equipment employed such as cooling towers, spray ponds, open box condensers etc.

6. *What level of microbial count should be maintained in the cooling tower?*

Ideally the cooling tower system should not be allowed to have bacterial/microbial growth beyond 50000 counts/ml.

7. *How are microbial treatments selected?*

Microbial treatments are selected by first analyzing representative water and slime samples to determine the types of organism present. Three general classes of chemicals are used in microbial control

- ✓ [Oxidizing biocides](#) literally burn up any microbe they come in contact with. Common oxidizers are chlorine, chlorine dioxide, and bromine, ozone, and organo-chlorine slow release compounds. Chlorine is one of the most widely used, cost effective biocides and is available in liquid, gaseous or solid form. Its effectiveness is increased when used with non-oxidizing biocides and biological dispersants. Ozone is now a day widely used to curb microbial growth.
- ✓ [Non-oxidizing biocides](#) kill the micro-organisms. They are effective where chlorine may not be adequate.
- ✓ [Bio-dispersants](#): These chemicals does not kill organisms, they loosen microbial deposits, which can then be flushed away. They also expose new layers of microbial slime or algae to the attack of oxidizing biocides. These

are an effective preventive measure because they make it difficult for the microorganisms to attach to the metal surfaces to form deposit.

A combination of all three generally makes an excellent program.

In fact, it has been unequivocally demonstrated that because of the unique surface characteristics of bio-films, their hydrodynamic and insulating properties far exceed those of an equivalent thickness of scale or corrosion deposits.

Of particular concern are the slime and spore formers which are difficult to control because of the protection afforded by the polysaccharide sheaths that they secrete and the organisms that metabolize either cellulose or lignin, resulting in structural weakness and eventual collapse of wooden tanks or towers.



SLUDGE OR FOULING

Under this heading are included dirt, mud, sand, silt, clay, scale salts, and other particulates of airborne origin or entering the system with the makeup water. Very often these suspended solids are tightly bound and cemented by corrosion products and organic matter.

1. What is fouling?

Fouling is the accumulation of solid material other than scale in a way that hampers the operation of plant equipment or contributes to its deterioration.

2. What influences fouling in a cooling system?

The most important factors influencing fouling are:

- Water characteristics
- Temperature
- Flow velocity
- Microbial growths
- Corrosion
- Contamination

3. How do water characteristics affect fouling?

Distilled water will not foul. However, most waters contain the dissolved and suspended materials that can cause a significant fouling problem under certain conditions.

4. How does temperature affect fouling?

Increasing temperature increases the fouling tendency. Because heat transfer surfaces are hotter than the cooling water, they accelerate fouling.

5. How does flow rate affect fouling?

At low flow rates typically 1 fps or less, fouling occurs due to natural settings of suspended material. At higher flow rates, 3 fps or more fouling can still occur but usually is less sensitive.

6. How does microbial growth affect fouling?

Micro-organisms can form deposits on any surface. In addition corrosive or iron depositing bacteria cause or utilize corrosion products, which subsequently deposit as voluminous foulants. All microbial colonies act as a collection site for silt and dirt, causing a deposit of different foulants.

7. How does corrosion affect fouling?

Corrosion can form insoluble corrosion products that migrate and mix with debris, process contamination, or microbial masses to aggravate fouling.

8. How does process contamination affect fouling?

Materials often leak from the process side of heat exchange equipment and can cause serious fouling problems in several ways.

- Depositing as insoluble products
- Providing nutrient for micro-organisms and causing severe microbial growth
- Reacting with scale or corrosion inhibitors to form insoluble foulants

9. How can fouling be controlled?

Fouling can be controlled mechanically or by the use of chemical treatments. The best method of control depends upon the type of fouling. Control of fouling in the cooling system involves three major tactics:

- ✓ Prevention: Whatever can be done to prevent foulants from entering the cooling system, this may require mechanical changes or addition of chemicals to clarify make-up water.
- ✓ Reduction: Steps taken to remove or reduce the volume of foulants that unavoidably enter the system. This may involve side stream filtering or periodic tower basin cleaning.
- ✓ Ongoing Control: Taking regular action to minimize deposition of the foulants in the system. This can include adding chemical dispersants and air rumbler or back-flushing exchangers.

10. How do chemical inhibitors work?

Charge-reinforcement and wetting agent dispersants act to keep foulants in suspension, preventing them from setting on metal surfaces or helping to remove fouling deposits that have already formed. The charge reinforcement dispersants cause the foulants to repel one another by increasing the electrical charges they carry. The wetting agents make the water wetter (reduce surface tension), inhibiting new deposit formation and possibly removing existing deposits. This action keeps the particles in the bulk water flow, where they are more likely to be removed from the system, either through blow-down or filtration.

11. What kinds of chemical are normally used?

- ✓ Charge reinforces – Anionic polymers
- ✓ Wetting agents – Surfactants

12. What is the most important factor in reducing fouling?

Continuous control of both the chemical and mechanical programs is the only way to reduce fouling.

13. What is Silt Density Index?

Silt Density Index is a measure of the fouling tendency of water based on the timed flow of a liquid through a membrane filter at a constant pressure.

14. What could be the affects of Fouling on cooling water system?

Where abrasive, sludge deposits can damage pump seals and in addition to their insulating nature can also promote "under-deposit" corrosion.

The answer to the aforementioned problems created by scale, corrosion, bio-fouling and sludge is, of course, a comprehensive water treatment program comprising scale

and corrosion inhibitors, micro biocides and dispersants coupled with adequate bleed off and appropriate equipment.

PART III – COOLING WATER TREATMENT APPROACHES

1 FILTRATION

- 1) **Objective:** The objective of filtration is to remove the suspended solids up to 2-mg/l levels.
- 2) **Method:** The method involves passing the water through a filtration media such as sand, anthracite, dual media, multimedia or multi layered gravel.
- 3) **Operation:** Sand filters provide clean water by reversing flow through the sand bed and backwashing dirt out the top of the filter. With this setup, dirty water enters the top of the filter through the over-drain assembly and is distributed over the sand media bed. The sand bed traps the particles and allows the filtered water to pass through the under-drain assembly and back to the cooling tower sump. As dirt accumulates, it causes a pressure differential across the filter. When the differential pressure reaches set point, flow through the sand bed is reversed, backwashing accumulated dirt out of the top of the filter and down the drain. After the media is cleaned, the filter goes back into normal filtration mode.

Although sand filters provide clean water, they use a high volume of backwash water, and over time, the sand media must be replaced. This can be a labor-intensive maintenance procedure.

4) **Type of Filtration:**

The filtration system could incorporate any of the following system:

- ✓ **Gravity filtration system:** The water flows through gravity across the media in an open top tank. It is a slow velocity system that requires larger foot print of equipment
- ✓ **Pressure Filters:** where pressurized flow moves across the filter media in a pressure vessel. It is a high velocity system that requires smaller foot print of equipment
- ✓ **Up Flow Filters:** is a type of pressure filters. The water moves under pressure from bottom to top across the filter media. This is useful even for handling

larger suspended solids as clarifier and often includes polymer dosing for better removal of suspended solids.

- ✓ [Ultra-Filtration](#): A low-pressure membrane filtration process that separates solutes in the 20-1000 angstrom (up to 0.1 micron) size range.

5) **Filtration Approaches**

Two basic approaches are used when sizing the filtration needs of say cooling tower; full-flow and side-stream.

- ✓ [Full-flow filtration](#) continuously strains the entire system flow. In this case, the filter typically is installed after the cooling tower on the discharge side of the pump. While this is the preferred method of filtration, for higher flow systems, it may be cost prohibitive.
- ✓ [Side-stream filtration](#), although popular, does not provide complete protection, but it can be effective. With side-stream filtration, a portion of the water is filtered continuously. This method works on the principle that continuous particle removal will keep the system clean. Manufacturers typically package side-stream filters on a skid, complete with a pump and controls. For high flow systems, this method is cost-effective.

Properly sizing a side-stream filtration system is critical to obtain satisfactory filter performance. There is some debate over how to properly size the side-stream system. Many engineers size the system to continuously filter the cooling tower basin water at a rate equivalent to 10% of the total circulation flow rate. For example, if the total flows of a system is 900 gal/min (a 300-ton system), a 90 gal/min side-stream system is specified.

A more accurate approach is to calculate the system's total water volume and filter it once per hour.

6) **Selecting a Filtration System**

When selecting a cooling water filtration system, a potential user should consider many factors. Manufacturers can provide an application questionnaire that will help you define your filtering needs and assist them in making recommendations. When approaching filter manufacturers, be prepared to answer the following questions:

- ✓ Is a full-flow or side-stream system desired?
- ✓ What is the system's flow rate?
- ✓ What size particles are in the system? What are the characteristics of the particles (sand, algae, etc.)?

- ✓ What is the budget for the system?
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2 PRETREATMENT CLARIFICATION

- 1) **Objective:** The objective of pretreatment clarification is to remove suspended solids and colloidal particles in water.
- 2) **Method:** The method involves retention of cooling water in settling tanks and dosing chemicals to expedite settling of suspended particles. The settling tank in engineering language is called 'Clarifier'.
 - The settling tank or clarifier is basically fabricated of structural steel, usually circular in shape with bottom made of concrete.
 - The dosing chemical consists of coagulant and lime.

The settled sludge is removed periodically. The sludge handling system consists of sludge pumps, sludge thickener and belt press.

Many a times, the clarifier is fabricated to serve water-softening purposes also. The system is known as clarifier-softener that in addition to removing suspended solids & silica also removes hardness. The water softening using ion-exchange principle is described below.

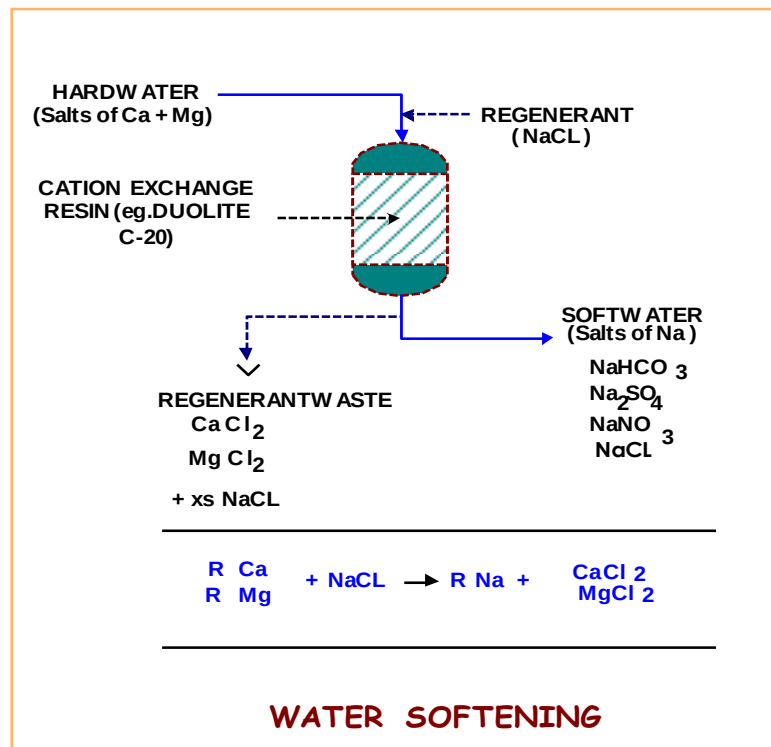
Coagulation: The destabilization and initial aggregation of finely divided suspended solids by the addition of a polyelectrolyte or a biological process.

Flocculation: Gentle stirring or agitation to accelerate the agglomeration of particles to enhance sedimentation or flotation.

3 SOFTENING BY ION EXCHANGE

The process involving removal of hardness producing salts from water is softening of water. The softening of water by ion exchange is relatively simple and effective. The process consists of passing hard water through a column of cation-exchange resin in the sodium form. The sodium on the resin replaces the objectionable calcium and magnesium ions.

Figure below illustrates the regeneration and service cycles of a water softener and shows the various ion exchange reactions that take place.



1) What factors impact the design of Ion Exchange system?

A reasonably accurate water analysis is required to design an ion exchange installation for water treatment. Following ions are most commonly found in a water sample.

- Alkaline Earth Cations: Ca⁺⁺ or Mg⁺⁺
- Alkaline Metal Cations: Na⁺, K⁺
- Total Alkalinity (ALK): OH⁻, CO₃⁻, and HCO₃⁻
- Total Salts of Strong Acids (TMA): SO₄⁻, Cl⁻, NO₃⁻

2) How is the water chemistry expressed?

The water chemistry in engineering parlance is described in grains per gallon and parts per million. It is common practice to express the amount of dissolved impurities as the cations and anions. These amounts may be expressed in terms of the ions themselves or as their calcium carbonate equivalents. The later is more prevalent among engineers.

3) *How to convert an ion concentration to CaCO₃ equivalent?*

To convert water analysis ppm as ion to ppm as calcium carbonate, follow the steps below or refer to a standard calcium carbonate conversion table in chemical books.

- ✓ Step #1: Find the equivalent weight of ion in question and divide it by 50, which is the equivalent weight of calcium carbonate.
- ✓ Step #2: Multiple the quotient by the part per million (ppm) concentrations as the ion.
- ✓ Step #3: After complete conversion to calcium carbonate equivalents, check the sum of the total cations must equal the sum of the total anions.

4) *Why Ion Exchange Resins are Important?*

Resin is a heart of ion-exchange system. The resins perform a function of exchanging the undesirable ions in the water to the desirable ones. There are many ion-exchange resins available today. By careful choice of the individual ion-exchange resin or in combination there off, it is possible to design many different types of systems to accomplish the same end. Any wrong selection shall have the impact on the final effluent from the system. It is strongly recommended to consult a manufacturer or an experienced water treatment design engineer for the right selection.

5) *What are Zeolites?*

Zeolites are complex silicates consisting of macromolecules of several metallic and non-metallic oxides. These are simply represented as Na₂Ze. They hold sodium ion in loose fashion and consequently when they are treated with a solution containing positive ions such as Ca & Mg, these shall be exchanged with sodium ions contained in Zeolite. Zeolite used for water softening purposes can be natural or synthetic. Synthetic inorganic zeolite, are more effective than natural zeolite, but are less durable. These are not capable of resisting acids, and therefore cannot be used in the exchange of hydrogen ions. The suspended impurities can clog the zeolite bed thus hindering the function.

6) *How to estimate the softener capacity?*

The softener capacity is governed by the amount of resin. The amount of hardness removed by one cubic foot of cation-exchange resin is directly dependent on the amount of regenerate salt used to convert the resin to the sodium form.

7) *What are the limitations of Softening?*

The sodium-cycle water softener removes the hardness from the water but allows the alkalinity to be carried forward. The alkalinities need to be treated with a process known as de-alkalization.

Waters exceeding hardness above 1500 ppm require somewhat different arrangements of equipment and techniques of regeneration.

4 DEALKALIZATION BY ION EXCHANGE

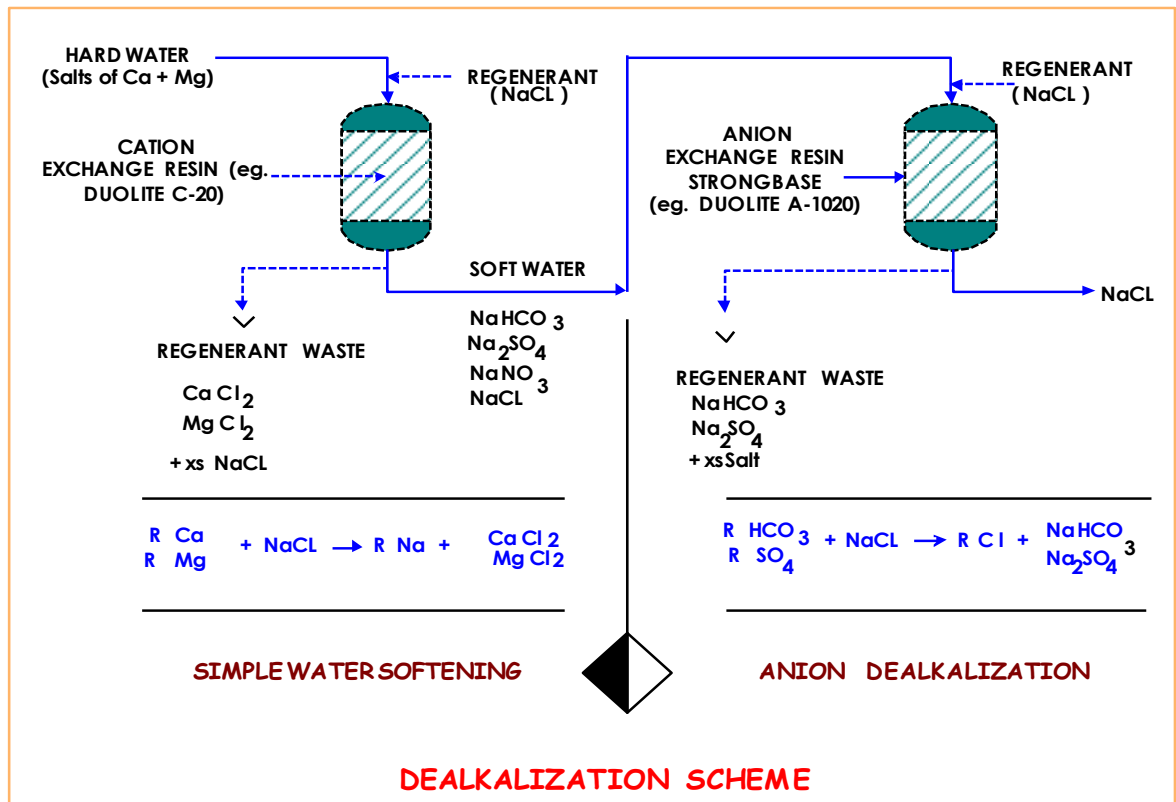
Several ion-exchange processes can be utilized to reduce alkalinity in raw water.

- ✓ The simplest and most straightforward process is chloride-cycle anion exchange. This process is usually preceded by a water softener. The sodium-cycle water softener removes the hardness from the water but allows the alkalinity to be carried forward.
- ✓ Another way is, the influent water is divided into two parallel flows. One portion is passed through a sodium-cycle water softener and the other portion is passed through a hydrogen-cycle cation-exchange unit. These two flows are then blended and passed through aerator or de-carbonator.

The hydrogen-cycle cation unit removes the hardness from the water and also creates some free mineral acidity.

When these two flows are blended, the free mineral acidity from the hydrogen-cycle cation unit reacts with the alkalinity from the water softener to produce carbon dioxide and water. The CO_2 can be eliminated by aeration or degasification.

A schematic representation of a chloride-cycle dealkalizer -- with the reactions that take place -- is illustrated in figure below:



Water Problem # 1 (Softening and De-alkalization)

When the total hardness to alkalinity ratio is less than one, a weak-acid cation resin is an effective way of treating water. Resin such as Duolite CC-3 is widely used in the industries, which simultaneously remove both hardness and alkalinity.

A weak-acid cation exchange resin is very useful where the hardness exceeds 3000 ppm. The scheme shown above is good for such a scenario.

Water Problem # 2 (Softening and De-alkalization)

If the total hardness to alkalinity ratio is greater than one, the following scheme could be more effective to achieve complete removal of both hardness and alkalinity.

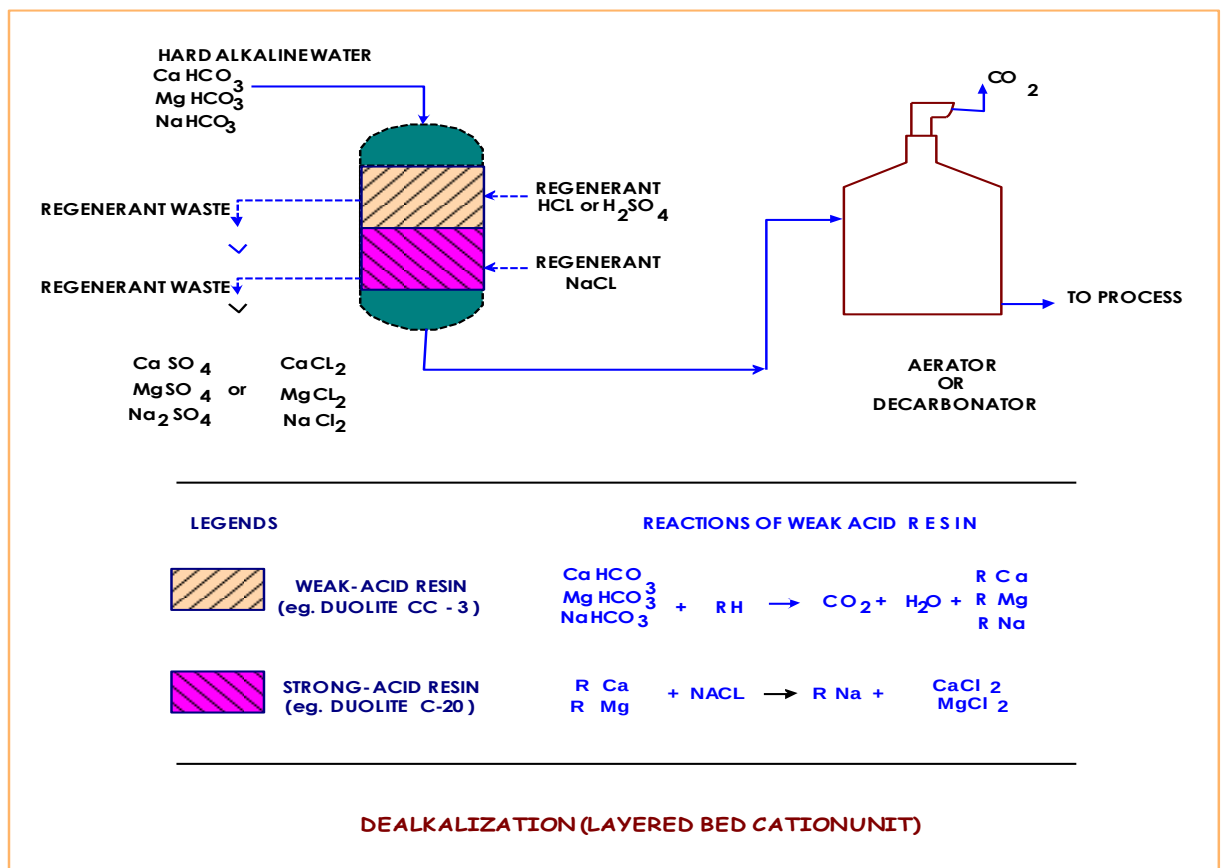
One of the commonly used techniques of producing soft, dealkalized water involves the use of a layered-bed cation unit. This system consists of a single tank ion-exchange unit with a layer of lower density weak-acid resin on a layer of higher density strong-acid resin.

The weak-acid resin is regenerated with a mineral acid and the strong-acid resin with sodium chloride.

The weak-acid resin removes the temporary or carbonate hardness and the strong-acid resin removes the non-carbonate or permanent hardness.

The effluent from this duo-bed unit is then passed through an aerator or de-carbonator for removal of CO_2 .

The reactions of the individual resins are illustrated in Figure below.



5 DEMINERALIZATION BY ION EXCHANGE

Demineralization of water by ion exchange is achieved by passing the water through cation and anion-exchange resins.

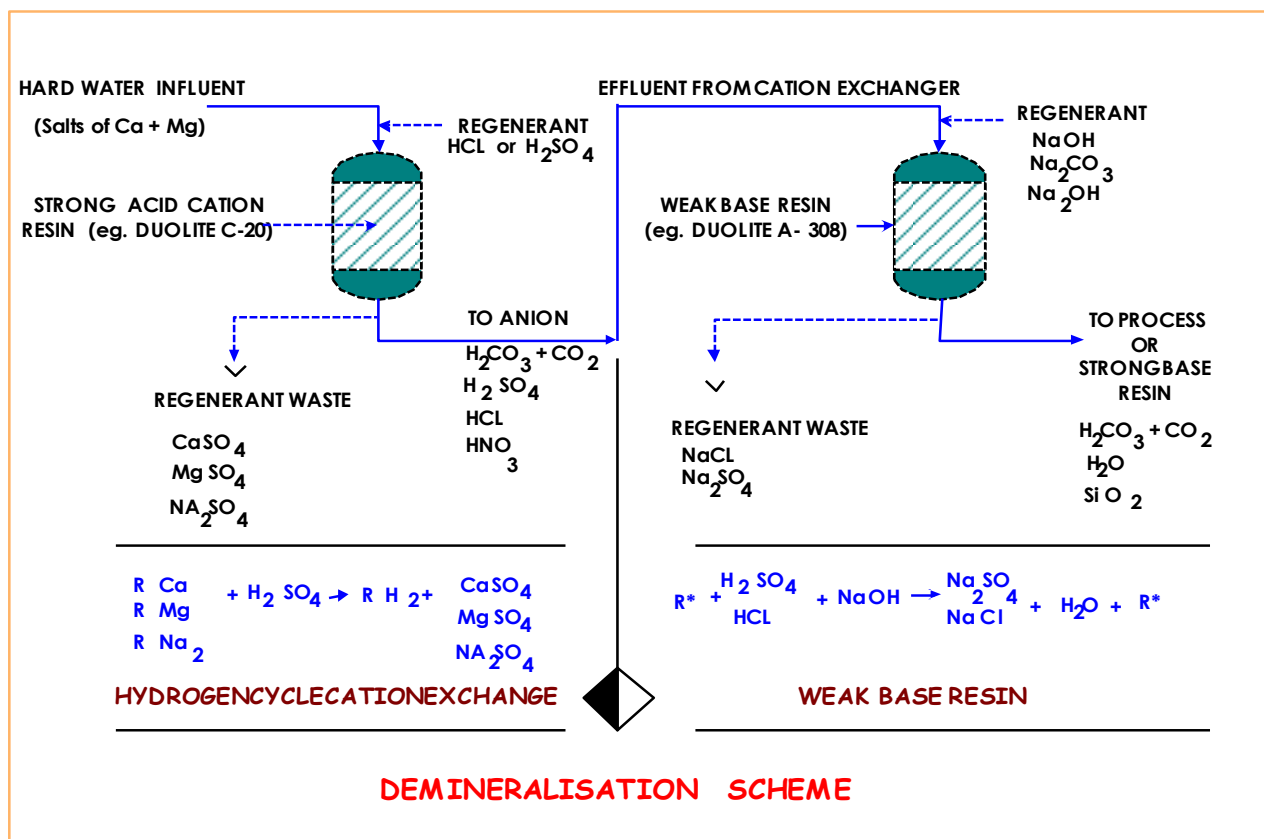
The cation exchanger in the hydrogen form exchanges hydrogen ions for the positively charged cations in the water. The effluent from such a unit is then carried forward to an anion-exchange resin.

The anion-exchange resin in the hydroxide form exchanges hydroxide ions for the anions in the water. This might be either a weak-base or a strong-base resin. A weak-base resin adsorbs the entire acid molecule and not just the chloride ion.

The process consists of a typical acid-base reaction, which forms the salt of that acid in water. In many applications, a strong-base anion resin follows the weak-base resin. The spent regenerant from the strong-base anion unit is sufficient to regenerate the weak-base anion resin in most cases.

The net result of this operation is replacement of the dissolved salts with water.

As mentioned before, it is possible to use many combinations of the various cation and anion-exchange resins to get the demineralized water.



6 REVERSE OSMOSIS (RO SYSTEM)

Osmosis is the natural passage of a liquid through a semi-permeable membrane, during which the liquid flows from a state of low concentration of solids or impurities to a state of relatively high concentration. Reverse osmosis is the reverse of the natural osmosis process that occurs in nature.

To treat water by the osmotic process, osmosis must be reversed to make the water flow from a state of high concentration of solids to a low concentration. This is done by applying pressure ranging from 400 to 2,000 psig to the high concentration side of the membrane; the result is high quality water.

It is highly efficient method of obtaining high quality water & cost effective, particularly for situations where water TDS is above 2000 ppm.

Other Facts on Reverse Osmosis

- Reverse osmosis systems are used to produce drinking water from seawater.
- Reverse osmosis process is generally preceded by thorough pretreatment filtration. A correct choice of pretreatment is very important as it influences the quality and quantity of the product, and above all, the life span of the module.
- With increasing operating pressure and temperature of the feed water, the capacity of the Reverse Osmosis (RO) increases.
- The capacity of the installation must be measured against the lowest feed water temperature. Since the rated output is based on 77° F (25° C), it must be divided by the appropriate temperature correction factor.
- Fouling can cause the capacity of the module to be reduced by about 20% at 400 psi (28 bars) and by 8% at 200 psi (14 bars) in three years.
- There are different theories about the water and salt transfer mechanism through the reverse osmosis membranes; one assumption is that capillaries are situated in the surface of the membrane through which the pure water flows; another refers to a solution-diffusion phenomenon.
- Reverse osmosis process does not allow the dissolved inorganic and organic matter to pass through the membrane; or only to a very small extent. In addition, organic matter as well as colloids and turbidity are almost 100% removed.
- Pure water is forced through the membrane and dissolved impurities remain on the feed side of the membrane.
- The recovery rate or permeate typically ranges from 25% for small (100 gal per day) systems to 75% for larger (10,000 gal per day) systems.
- The single pass RO systems are employed where water TDS is about 150 mg/l to 1500 mg/l.
- Double pass RO systems are employed where water TDS is above 1500 mg/l.



CONCLUSION AND COMMON PRACTICES

There are several known treatment approaches in vogue, but the application & selection depends on various conditions viz. year round atmospheric conditions, space availability, water quality and operational economics. A combination of mechanical as well chemical treatment is desired in certain cases. A filtration system does not replace the need for

water treatment, or vice versa. Chemicals cannot remove dirt just as filters cannot control water chemistry. A filtration system shall only complement the water treatment program.

1) Dedicated water treatment system v/s the Centralized system?

The choice of cooling water treatment system whether centralized or dedicated depends on the operating conditions, level of treatment and the cost. Generally the pre-treatment is made common for the entire facility and the dedicated water treatment system is recommended on a dedicated system basis. Different equipments in a facility operate at varying conditions. For water conditioning to be effective the operating conditions viz. the temperature & water chemistry. The water treatment program is selected appropriately per each requirement. The reasons are illustrated below:

- It is quite likely that if water quality is treated to use at high temperature services; say at 140/150°F, the equipment might corrode at lower temperature of say 70/80°F.
- On contrary if water quality is conditioned to use at lower temperature then the same water could be scaling for surfaces at high temperature.
- The cooling tower treatment in open re-circulation loop is different from the jacket cooling of process equipment in closed circuit. The closed circuit conditioning is generally dosage of nitrite and molybdates. The microbial growth is normally not a problem in closed loops; corrosion and fouling is the main concern.

2) What do monitoring and control mean?

For every treatment program there are specific chemical concentration ranges, where it functions best and provides the intended protection. If not properly controlled any chemical program can fail, leading to possible lost production, increased maintenance cost and increased energy usage.

For daily system control, easy tests are available for things such as conductivity, pH, alkalinity, hardness, and chlorine treatment levels. The necessary control tests must be consistently run and corrective action taken when one variable is out of balance. Daily control is the foundation for a successful treatment program.

Several monitoring tools are available to determine the conditions of cooling system:

- ✓ Corrosion Coupons – To establish relative corrosion rates of different metals in cooling systems, small metal strips called corrosion coupons can be used. Ideally the corrosion coupons should be installed in re-circulating system for period of 6 to 12 months, then removed, cleaned and weighed again. The

difference in the coupon's weight before and after exposure is used in calculating the corrosion rate.

- ✓ Corrater- An electronic instrument that measures the corrosion and pitting tendencies in a cooling system. It provides an instantaneous, direct reading of the system's corrosion rate in mils per year (mpy) when its probe is inserted into the cooling water.
- ✓ Corrosion Test Rack – Evaluate the effectiveness of corrosion inhibition programs on non-heat transfer surfaces. It is designated to be used with either corrosion coupons or corrator probes.
- ✓ Deposit monitor- An aid in examining the performance of a cooling water program. A sample tube of proper metallurgy is surrounded by a glass jacket. The metal surface sample can be observed at any time during the testing. Heat transfer rates can be simulated using a cartridge heater and cooling water flows regulated with a control valve.

3) *What are general combinations of resins to achieve reduction in dissolved solids?*

There are various possible combinations and arrangements of ion-exchange resins. Each resin or combination is effective for controlling a particular parameter more effectively. It is recommended to consult a water treatment equipment supplier for appropriate selection. The few resins are:

Resin	Function
Zeolite Softener	To remove hardness i.e. Ca, Mg
Weak Acid Cation (WAC)	To remove the weak acid cations, i.e. hardness, Ca^{++} or Mg^{++} associated with alkalinity OH^- , CO_3^{--} , and HCO_3^{--}
Strong Acid Cation (SAC)	To remove all the cations & anions including Ca^{++} , Mg^{++} , Na^+ , K^+
Weak Basic Cation (WBC)	To remove salts of strong acids, SO_4^{--} , Cl^- , NO_3^-
Strong Base Anion (SBA)	To remove all anions including SiO_2 and CO_2
Mixed Bed (MB)	It is a mixture of SAC and SBA resins. The function is to polish and remove residual remaining ions in water.

4) *What effect does acid cleaning have on a cooling system?*

Acid removes corrosion products and some mineral contaminants, but has little effect upon organic materials. With improper application it may attack system metal and cause severe metal attack. Improper flushing will leave metal surfaces in a highly reactive state, which makes them especially vulnerable to corrosion attack

5) What are the common chemical inhibitors used for water treatment?

The common chemical inhibitors compounds are:

1. Chromates: These are generally used with zinc and poly-phosphates. When chromates are used alone, the level should be maintained otherwise it would promote corrosion. Few countries/states do not permit the use of chromates because of its toxic nature.
2. Poly-Phosphates: These basically extend the solubility limit of Calcium. The main limitation of these are that in case pH increases beyond 7.3, these will be converted into ortho-compound, which will react with calcium and form the sludge.
3. Zinc: These provide film of zinc hydroxide. If pH = 6.5, maintenance is must. If pH > 6.5, zinc will go to the solution. If pH < 6.5, it will precipitate. It will tend to absorb the suspended particulates, which shall lead to higher turbidity.
4. Nitrates: These are anodic inhibitors. High level of sulphates and chlorides will affect its performance that leads to high turbidity.
5. Silicates: This cannot be used if pH is high (> 7) and hardness is over 250 ppm.
6. Sodium Meta Phosphate (SHMP): This is effective in a sense that it delays the solubility limit of calcium salts and therefore the scale formation is delayed. The disadvantage however is that it degenerates into ortho-compound and require pH to be controlled with in 6.5 to 7.4. It also acts as food for bio fouling. The latest developments are employing Amino Trimethylene Phosphonate Acid (ATMP) and Hydroxyl Ethylketene di-Phosphonate Acid (HEDP) that does not have the limitations of SHMP.

6) What are the common industry practices to condition the cooling water?

- ✓ In practice an estimation of saturation index provides a satisfactory solution to estimate whether water is scaling or corrosive tendencies.
- ✓ The provision of anodic protection by using polyphosphates and chromium oxide to the extent of 40 ppm and 20 ppm respectively ensures protection to

the extent of 1-3 mile per year. Addition of 5/10 ppm of polycrymides benefits the system by keeping CaCO_3 etc in suspension.

- ✓ To counter the presence of organic matter and algae presence of 6/7 ppm of free chlorine is desired.
- ✓ Several new generic water conditioning and protective chemicals are available today, for less detailed water analysis. This is however a risky and not a recommended option for long run.
- ✓ The plants with high capital investments and high intensity of energy resort to safe process water demineralization and find it economical and worthwhile to ensure highly efficient operations.

Course Summary

In today's world of expensive energy and replacement costs, it is more vital than ever, for heat exchange equipment to be kept free of insulating deposits. The four principal sources of these deposits are: scale, corrosion, biological growths and sludge. Scale deposits and corrosion products on the tube surfaces reduce heat transfer efficiency and increases energy costs. These factors are important for another reason: they have a direct effect on equipment life.

A chemical program in addition to the cooling water treatment is the only way to insure that deposit formation does not become a problem. Such steps basically will ensure not only operation efficiency but also a significant saving of energy. Water conditioning alone becomes a very important aspect of energy conservation program.

In conclusion it may be emphasized that properly conditioned and treated water is desirable activity whether it is for power generation, fertilizers, petrochemicals, steel, paper, air-conditioning, refrigeration or ice manufacturing or any other industry. In industrial process, manufacturing and air-conditioning applications, it is desirable to remove or reduce the hardness of water before it is used. For large capital-intensive energy projects such as power generation and petrochemical industry, the elaborate cooling water treatment schemes need to be carefully evaluated to enhance overall productivity.

Related Reading

Cooling Water System- An Overview of Cooling Towers

The course [Cooling Water System – “An overview of Cooling Towers”](#) provides the system details for the open re-circulation cooling water systems. The 4-hours course summarizes the important features of the cooling tower systems.

Cooling Water Conditioning and Its relevance to Energy Conservation in HVAC Applications

The water-cooled air-conditioning systems utilized in bigger facilities consume large chunk of power. It is observed, that the performance and life of the air-conditioning systems could be significantly enhanced with proper cooling water treatment. An effective water treatment program could contribute to saving good amount of dollars on electrical energy, offsetting the cost of treatment. The concepts have been discussed exclusively in another course '[Cooling Water Conditioning and its relevance to Energy Conservation in HVAC applications](#)'.

Water Supply- Water Treatment

This online course presents detailed information on water quality standards and design criteria for water treatment processes. The contents also cover criteria to be followed in determining the necessity for and the extent of treatment, and procedures applicable to the planning of water treatment projects. The course provides comprehensive information and is titled “ Water Supply-Water Treatment” (number C-128)