COOLING WATER BASICS

What is the need for cooling water systems?

The cooling water system maintains the correct temperatures and pressures. Most industrial production processes need cooling water for efficient, proper operation. Refineries, steel mills, petro-chemical manufacturing and chemical processing plants, and electric utility all rely on the cooling water system to control temperatures and pressures by transferring heat from hot process fluids into the cooling water, which carries the heat away. As this happens, the cooling water heats up and must be either cooled before it can be used again or replaced with fresh make-up water.

What is the cooling process?

Cooling involves the transfer of heat (calories or Joules) from one substance to anther The substance that loses heat is said to cooled and the in that receives the heat is referred to as the coolant. All cooling systems rely on this give and take action, with water being the most widely coolant.

Why is water used for cooling?

The factors that make water an excellent coolant are:
. It is normally plentiful, readily available, and inexpensive
. It is easily handled
. It can carry large amounts of heat per unit volume
. It does not expand or compress significantly within normally encountered temperature ranges.
. It does not decompose

What are the sources of cooling water?

Fresh Water- This is the primary source of make-up for cooling water systems. Fresh water can be surface water (rivers, streams, reservoirs) or ground water (shallow or deep well waters). In general, ground water supplies are more consistent in composition and contain less suspended matte than surface water supplies, which are directly affected by rainfall, erosion, and other environmental conditions.
Salt water and waste water Because of environmental considerations, water cost and water availability, some plants are now using salt water and waste water treatment plant effluents as sources of cooling water. Close attention to design and treatment of cooling system using these sources of water is critical for reliable performance and long life.

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What are some important properties in cooling water chemistry?
The important properties are:

Conductivity –
This is the measurement of water's ability to conduct electricity. In cooling water, it indicates the amount of dissolved mineral and gases in the water. Conductivity is measured in micromhos and can very form a few for distilled water to over 10,000 for salt water.

pH-
Gives an indication of the relative acidity or basicity of water. The pH scale runs from 0 to 14, with 0 representing maximum acidity and 14 maximum basicity.

Alkalinity-
In cooling water two forms of alkalinity play a key role. These are carbonate (CO3) and bicarbonate (HCO3) alkalinity.

Hardness-
This refers to the amount of calcium and magnesium minerals present in the water. The hardness in natural water can very from a few parts per million (ppm) to over 800 ppm.

Why are these water properties important in cooling water systems?

Each of the key water chemistry property has a direct impact on the four amin problems of cooling water systems: Corrosion, scale fouling and microbiological contamination. These properties also affect the treatment programs designed to control the problems.
Conductivity- Cooling water treatment program will function within specific ranges of conductivity: the range will be dependent upon the particular cooling water system's design, characteristic and the type of the chemical program.

pH-
control of pH is critical for the majority of cooling water treatment programs. pH is below recommended ranges, the changes for scale formation increase. The effectiveness of many biocides also depends on pH; therefore high or low pHs may allow the growth and development of microbiological problems.

Alkalinity-
Alkalinity and pH are related because increase in pH indicate increases in alkalinity and vice versa. As with pH alkalinity below recommended ranges increase the change for scale information. When corrosion and scale problems exist, fouling will also be a problem.
Hardness-
Hardness levels are usually associated with the tendencies of cooling water to be scale forming or not. Chemical programs to prevent scale can function only when the hardness level stays within the specified range. Some corrosion control programs require certain hardness level to function correctly as corrosion inhibitors, so it is important to make sure hardness levels are not low in these programs.

What are the common types of cooling water systems?

Although no two cooling water systems are alike, there are really only three basic designs.
. Open recirculating systems
. Once- through systems
. Closed recirculating systems

How are these three systems different?

The open recirculating system is the most widely used industrial cooling design. It consists of pumps, heat exchanger, and cooling tower. The pumps keep the water recirculating through heat exchangers where it picks up heat and on to the cooling tower where heat is released from the water through evaporation.
Because of evaporation, the water in open recirculating systems undergoes changes in its basic

Chemistry.

In once-through systems, the cooling water passes through heat exchange equipment only once. Because large volume of cooling water are used, the effluent water temperature increases only slightly. The Mineral content of the cooling water remains practically unchanged as it passes through the system. Closed recirculating systems use the same cooling water repeatedly in a continuous cycle. First, the water absorbs heat from process fluids, then releases it in another heat exchanger.

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.

How does water velocity affect corrosion?

High-velocity water increase corrosion by transporting oxygen to the metal and by carrying away corrosion products at a faster rate. High velocity can also cause corrosion of metal surfaces, protective films, and oxides. When water velocity is low, deposition of suspended solids can establish localized corrosion cells, there by increasing corrosion rates.

How does temperature affect corrosion?

Below 70$_0$C, every 10 C increase in temperature causes corrosion rates to double. Above 70 ^{0}C, additional temperature increases have relatively little effect on corrosion rates in cooling water systems.

How does microbial growth affect corrosion?

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

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 systems, choose corrosion-resistant materials to Minimize the effect of an 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.

How do chemical corrosion inhibitors work?

Chemical inhibitors reduce or stop corrosion by interfering with the corrosion mechanism. Inhibitors usually affect either the anode or the cathode.
Anodic corrosion inhibitors-establish a protective film on the anode. Though these inhibitors 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 surface whether anodic or cathodic.

What inhibitors are commonly used for cooling water system?

Mainly anodic: Chromates, Nitrites, Orthophosphates, Silicates
Mainly Cathodic: Bicarbonates, Metal cations, Polyphosphates
General: Soluble oils other organics

Does the type of cooling systems affect treatment applicable 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 of treatment because the water does not chance in composition significantly while passing through equipment.
In an open recirculating system more chemical must be present because the water compositions changes significantly through the evaporation process. Corrosive and scaling constituents are concentrated. However, treatment chemical also concentrate by evaporation; therefore, after the initial dosage. Only moderate dosages will maintain the higher level of treatment needed for these systems.
In a closed recirculating system water composition remains fairly constant. There is very little loss of either water or treatment chemical.

What is the most important factor in an effective corrosion inhibitor program?

Consistent control of both the corrosion inhibitor chemicals and the key water characteristics. No program will work without proper control.

COMMON COOLING WATER PROBLEMS SCALE

What is Scale?

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

- Tempreature
- Alkanlinity or acidity (pH)
- Amount of scale forming material present
- Influence of other dissolved materials, which may or may not be scale-forming.

How do the above factors increase the amount of scaling?

As any of these 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. For examples as pH or 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.
When the amount of scale-forming material dissolved in water exceeds its saturation point, scale may result. In addition, other dissolved solids may influence scale forming tendencies.
In general the higher the level of scale-forming dissolved solids, the greater the chance of scale formation.

How can scale formation be controlled?

There are four basic means to control scale.

- Limit the concentration of scale forming minerals by controlling cycles of Concentration or by removing the minerals before they enter the system. " Cycles Of concentration" is the ratio of the make up are to the blow down rate.
- Feed acid to keep the common scale-forming minerals (such as calcium Carbonate) dissolved.
- Treat with chemicals designed to prevent scale.

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Why do cooling water problems exist?

If left untreated, cooling water systems provide an environment where the four main cooling problems will exist.

Corrosion –
Water tends to convert metals (such as mild steel) to their oxide states.

Scale-
Water impurities, such as calcium and magnesium hardness can precipitate and deposit deposit depending on their concentration, water temperature, pH, alkalinity, and other water characteristics.

Microbiological Contamination –
Cooling water systems offer a favorable environment for microorganisms to grow and cause problems.

Fouling –
Suspended solids from either external or internal sources can cause deposits.

What are the effects of cooling water problems?

If left uncontrolled, the cooling water problems either alone or together, can cause:

- Increased maintenance cost.
- Reduced heat transfer efficiency and there fore greater energy losses
- Possible production cutbacks or shutdowns.

CORROSION

What is 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 (electrons) 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.

Are copper, aluminum alloys, and stainless steel's subject to corrosion as mild steel?

In general, these metals corrode more slowly than mild steel. However, in some waters these metals may be subject to serve localized (or pitting) attack. In addition, dissolved gases, such as H2S (Hydrogen sulphide) or NH3 (ammonia) are frequently more destructive to these metals than to mild steel.

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What ate the different types of corrosive attack?

Many different types of corrosion exits, but they can often be 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 by generalized attack contributes to fouling problems. Localized (or pitting) attack exists when only small areas of the metal corrode. Pitting is the most serious from of corrosion because the action is concentrated in small area. Pitting may perforate the metal in a short time.
Galvanic attack can occur when two different metals are in contact. The more actives metal corrodes rapidly. Common examples in water systems are steel and brass, aluminum and steel, zinc and steel, and zinc and brass. If galvanic attack occurs, the metal named first will corrode.

What water characteristics affect corrosion?

The most important factors are
- Oxygen and other dissolved are
- Dissolved or suspended solids
- Alkalinity or acidity (pH)
- Velocity
- Temperature
- Microbial activity

How does oxygen affect Corrosion?

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

How do dissolved out suspended solids affect corrosion?

Dissolved solids can affect the corrosion reaction by increasing the electrical conductivity of the water. The higher the dissolved solids concentration, the greater the conductivity and the more likelihood of corrosion. Dissolved chlorides and sulfates are particularly corrosive. Suspended solid can influence corrosion by erosion or abrasive action, and they can settle on metal surface to set up localized corrosion cells.

FOULING

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.
Examples of common foulants are:
- Dirt and Silt
- Sand
- Corrosion products
- Natural organics
- Microbial masses
- Aluminum phosphates]
- Iron phosphate

What influences fouling in a cooling system?

The most important factors influencing fouling are:
- Water characteristics
- Temerature
- Flow velocity
- Microbial growths
- Corrosion
- Contamination

How do water characteristics affect fouling?

Distilled water will not foul. How ever, Most waters contain the dissolved and suspended materials that can cause a significant fouling problems under certain conditions.

How does flow rate affect fouling?

At low flow rates (0.5 meter per second or less), fouling occurs due to natural settling of suspended material. At higher flow rates (One meter per second or less), fouling occurs due to natural settling of suspended material . At higher flow rates (One meter per second or more), fouling can still occur, but usually is less severe.

How do microbial growths affect fouling?

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

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.

How does process contamination affect fouling?

Material that leaks form the process side of heat exchange equipment can cause serious fouling problems in several ways:
- Depositing as nutrient for microorganisms and causing severe microbial growths.
- Reacting with scale or corrosion inhibitors to from insoluble foulants.

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How can fouling be controlled?

Fouling can be controlled mechanically or by the 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 minimizeze deposition of the foulants in the systems. This can include among chemical dispersants and air rumbling or back-flushing exchangers.

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 wetter (reduce surface tension),
Inhibiting new deposits. This action keeps the [particles in the bulk flow, where they are more likely to be removed from the system, either through blow down or filtration.

What kinds of chemicals are normally used?

Charge reinforces- Anionic polymers
Wetting agents – Surfactants

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.

Microbiological Problems

What is microbiological contamination?

The uncontrolled growth of microorganisms can lead to deposit formation which contribute of fouling, corrosion and scale. The accompanying table(Table 1) lists troublesome microorganisms and the problems they create

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What are microbial slimes?

Microbial slimes are masses of microscopic organisms and their waste products. These slimes are usually characterized by their gooey feeling and can be plant or animal.

Are all organisms found in a cooling water system harmful?

No. Some organisms do not create slime deposits and do not promote metal corrosion. The presence of large numbers of these harmless organisms, however, indicates that conditions are ideal for the growth of harmful organisms.

How do microorganisms enter a cooling water system?

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

What factors contribute to microbial growth?

The most important factors is the degree of microbial contamination. Next in importance are:

- **Nutrient**s: For instance, hydrocarbons or other carbon source can serve as food For slime-forming organisms.
- **Atmosphere**: Organism growth depends upon the availability of oxygen or carbon Dioxide.
- **Location:** Such factors as the amount of light and moisture significantly affect Growth rates.
- **Temperatures:** Organisms that make up slime tend to flourish between 40 and 1500 F

PRINCIPAL CLASSES OF TROUBLESOME MICROORGANISMS
CLASSIFICATION DESCRIPTION COMMON PROBLEMS

Table 5.1 Algae Growth conditions

Algae grouping	Examples	Conditions for growth t Temperature	pH
Green	Chlorella (common unicellular) Ulothrix (filamentous) Spirogyra (filamentous)	86 to 95 ^{o}F	5.5 to 8.9
Blue – green (contain blue pigment)	Anacystis (unicellular slime former) Phormidium (filamentous) Oscillatoria (filamentous)*	95 to 104 ^{o} F	6.0 to 8.9
Diatoms (contain brov pigment and silica cell walls)	Flagilaria (long and thin in series) Cyclotella (wheel shaped) Diatoma (larger–rectangular or tapered)	64 to 96 ^{o} F	5.5 to 8.9

* Under certain conditions, Oscillatoria can acclimate to waters with temperaturws as high as 186 ^{o} F and pH values as high as 9.5

Table 5. 2 Fungi growth conditions.

Type fungi	Examples	Characteristics	Conditions For growth Temp.	pH	Problems Created
Filamentous mould	Aspergillus, Pencilium, Mucor, Fusarium, Alternaria	Black, Tan, Blue, Yellow, Green White gray ,Pink,Brow	32 to 100 ^{o} F	2 to 8 with 5.6 optimum	Surface root wood , bacteria like slimes
Yeast-like	Torula Saccharomyces	Leathery rubbery growt usually pigment	32 to 100 ^{o} F	2 to 8 with 5.6 optimum	Bacteria like Slimes discoloration water and wood
Basidiomycetes	Poria Lenzites	White or brown	32 to 100 ^{o} F	2 to 8 with 5.6 optimum	Internal decay wood

Table 5.3 Bacteria growth conditions.

e Bacteria	Examples	Conditions for growth Temperature	pH	Problems created
Aerobic capsulated	Aerobacter aerogenes Flavobacterium Proteus vulgaris Pseudomonas aeruginosa Serratia Alcaligenes	68 to 104 ^{0} F	4 to 8 with 7.4 optimum	Severe bacterial slimes are formed
Aerobic spore forming	Bacillus mycoides Bacillus subntilis	68 to 104 ^{0} F	5 to 8	Bacterial slimes . Spores produced are Difficult to destroy
Aerobic sulfur	Thiobacillus thiooxidans	68 to 104 ^{0} F	0.6 to 6	Sulfur or sulfides are oxidized sulfuric acid
Anaerobic Sulfate reducing	Desulfovibrio Desulfuricans	68 to 104 ^{0} F	4 to 8	Grows under aerobic slime causing corrosion . Results in formation or hydrogen sulfide
Iron	Crenothrox Leptotrix Gallionella	68 to 104 ^{0} F	7.4 to 9.5	Precipitates ferric hydroxide in sheath like coating around cell. Forms bulky slime deposits .

***Normally, all of these bacteria have a temperature range of 68 to 104 ^{o} F . Under certain conditions some species will grow at temperatures from 40 to 158 ^{o} F,**

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Can slime cause scale formation?

Yes Slime can cause or accelerate the rate of scale formation. Slime can cause treatment chemicals for scale to be ineffective. When deposits form, heat transfer is reduced. This causes possible production cutbacks and higher energy cost.

Can slime cause Fouling?

Slime masses themselves are foulants. They provides excellent sites for the deposition of other foulants. Other microorganisms and suspended solids can become part of the fouling deposit.Although many organisms tend to die at high temperatures, the remaining debris still fouls metal surfaces.

Can Slime cause corrosion?

Certain organisms, for example the sulfate-reducing type, generate corrosive hydrogen sulfide which cause severe pitting attack. In addition, slime can accelerate corrosion by deposition on the metal and preventing protective film formation.

Do organisms affect specific areas in a cooling system?

Generally, microbial organisms form colonies at point of low water velocity. Heat exchangers are therefore subject to microbiological contamination. Similarly cooling towers are subject to fouling as well as surface and internal rot.

What factors must be considered ion planning an effective microbial control program?

The most important factors are:

- Type 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.

Sources of contaminations such as organisms and nutrients carried into the system. These factors can influence the growth of troublesome organisms and affect the microbial control treatments.
Each systems must be evaluated, treated and handled individual.

How are microbial treatment selected?

Microbial treatment is selected by first analyzing representative water and slime samples to determine the types of organisms present. Specific biocides most toxic to the predominant organisms are then chosen. Treatment may be varied should any important factors change.

What types of chemicals are used for microbial control?

Three general classes of chemicals are used in microbial control:

- Oxidizing biocides
- Non- oxidizing biocides
- Biodispersants

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What are oxidizing biocides?

Chemicals called "oxidizing biocides" literally burn up any microbe they come in direct contact with. Common oxidizers are chlorine, chlorine dioxide, bromine, ozone, and organo chlorine slow-release compounds. Chlorine is one of the most widely used, cost effective biocide, and is available in liquid, gaseous, or solid form. Its effectiveness is increased when used with non-oxidizing biocides and biological dispersants.

What are non-oxidizing biocides?

These are Organic compounds utilized in killing microorganisms. They are effective in areas or systems where chlorine may not be adequate.

What are biodispersants?

These chemicals do not kill organisms; they loosen microbiological deposits, which can then be flushed away. They also expose new layers of microbial slime and algae to the attack of oxidizing biocides. Bio dispersants are an effective preventive measure, because they make it difficult for the microorganisms at attach to the metal surfaces to form deposits.

PRETREATMENT, MONITORING AND CONTROL

What is pretreatment?

Pretreatment is the preparation of the cooling water system to insure that the treatment program can work effectively from startup.

Why is cooling water system pretreatment needed?

New systems or existing ones being returned to service can contain significant amounts of contaminating material. Films of oil or grease, general coatings or spots of rust, dirt and sand always remain in newly constructed systems. These materials do not represent faulty construction they result form conditions existing during construction.

In systems taken off line, deposits can be present as the result of scale, corrosion, fouling, or microbiological contamination. If these materials are not removed through effective pretreatment, the subsequent chemical program will not be effective.

What are the steps in system preparation and start-up?

To benign a cooling water systems protection program successfully the following preparation and start-up procedures must be followed.

- System cleaning
- Application of special pretreatment chemicals
- Initial high does applicable of corrosion inhibitors
- Ongoing application of corrosion inhibitors at maintenance levels.

Does water flushing or hydro testing remove new system contaminants?

Water flushing or hydro testing may reduce contaminants but not to any great extent. In addition, the untreated water and the unprotected metal surfaces react to form additional corrosion products.

What effect does acid cleaning have on a cooling systems?

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.

When should pretreatment chemicals be applied?

As soon as possible after construction. Pretreatment chemicals can be applied during or immediately after hydro testing. The sooner a system is pretreated after construction the more complete protection it will have. The same applies for equipment that had been taken offline. Pretreatment should take the necessary maintenance has been done and the unit is going back in service.

What is meant by monitoring and control? Why visit important?

For every treatment program there are specific chemical concentration range 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.

What tools are available for monitoring and control?

For daily system control easy tests are available for things such as conductivity, pH, alkalinity
Hardness, chlorine and treatment levels. The necessary control tests must be A consistently run and corrective action taken when one variable is out of balance. Daily control is the foundation of every successful treatment program.
Are automatic System available for monitoring and control?
An automatic system is an excellent addition to any treatment program where pH control is important. However, for proper operation, these systems need periodic maintenance and attention.

What are some methods for determining conditions in a cooling system?

Several Monitoring tools are available:
Corrosion Coupons- The establish relative corrosion rates of different metals in cooling systems, small metal, strips called corrosion coupons can be used. These preweighed coupons are placed in the systems for at lest 30 days, then removed, cleaned, and weighted again. The difference in the coupon's weight before and after exposure is used in calculating the corrosion rate.

The Corrater-

An electronic instrument that measures the corrosion 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 heat transfer