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# White Paper

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## A Reliable Alternative to Chemicals for Cooling Water Treatment

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# Use Water for Efficient Cooling

There are many problems associated with using water as a cooling media, including such things as limited supply, cost, corrosion, bacteria and scale formation. With all its problems, why would anyone want to cool their building or process with water? Why not use air since it is free and does not have the difficulties associated with maintaining a cooling tower? Air is such a poor heat transfer media that the energy required to operate the equipment is significantly greater than when water cooled chillers are used.

A study presented by the Cooling Technology Institute showed that a typical 400 ton air-cooled chiller would use 58% more energy than the water-cooled centrifugal chiller. Using water results in an annual cost savings of over \$39,000.

## Using Water to Transfer Heat

To transfer heat one must move heat from one area to another. This is what a window air conditioner does. It moves the hot air from the room and ejects it outside. When one uses water for heat transfer, one can move much larger amounts of heat from one place to another than would be practical by using air alone. This is the basic reason that water cooled chillers can save so much energy. To function, the chilled water system will consist of several parts.

- 1) A **Cooling Tower** to reject heat from the Chiller to the air by evaporation of water. The cooled water goes back to the Chiller and the heated water is cooled as it falls down through flowing air. Water cooled systems recycle about 97% of the total water while the remaining 3% is lost to evaporation and bleed. Typically, one gallon of water evaporated will cool 100 gallons of recirculated water 10°F. A small amount of water must be bled from the tower to control the build up of dissolved solids or excessive fouling can occur.
- 2) An **Evaporative Condenser** also rejects heat from the Chiller by evaporation of water. The only difference is that instead of sending the water down to a remotely located chiller plant, the water is sprayed directly on the tubes containing hot refrigerant. Otherwise, the Evaporative Condenser behaves much the same as the Cooling Tower.
- 3) A **Closed Loop** is many times used to transfer the chilled water to the different air handling units or process heat exchangers in a facility. The closed loop is normally not left open to air and only loses a small amount of water to evaporation and leaks. Even so, closed loops can be subject to corrosion and biological fouling.

## Typical Water Issues

Any time one has a contained volume of normal drinking water, a number of potential problems must be addressed:

### Scale

Scale normally results from naturally occurring minerals that are dissolved in the water. These minerals are concentrated by evaporation. When concentrated or heated some of the minerals do not stay in solution and precipitate forming a surface deposit known as scale. This is the white deposit seen inside a glass coffee pot. While many mineral groups can contribute to hard scales such as the phosphates, sulfates and silicates, the carbonate group is the most common problem. The mineral responsible for forming a majority of scale deposits is calcium carbonate ( $\text{CaCO}_3$ ). Calcium carbonate and other minerals that dissolve in rain water make the water "hard".

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Scaling in cooling towers and chillers is indicated by direct inspection or by carefully monitoring the rate heat is transferred. Since scale is insulating, it reduces the amount of heat transferred through the tubes of a heat exchanger, thus reducing capacity and efficiency of the system.

### Biological Activity

Bacteria, protozoa and algae can grow in the water found in cooling towers and closed loops. This growth not only can lead to an unsightly, smelly mess, but more importantly it can lead to significant loss of energy, health risks, and increased system downtime due to repairs. Biological activity can lead to the development of thick biofilms that can plug pipes and heat exchangers as well as help amplify disease organisms such as those that cause Legionella.

A good indicator of biological activity is the Heterotrophic Plate Count (HPC). This procedure measures the number of colony forming units (cfu) of bacteria floating in the water. The Cooling Technology Institute recommends that the HPC be kept lower than 10,000 cfu/ml to prevent Legionella outbreaks.

### Metal Corrosion

Corrosion is a very complex process that results in the oxidation of metals that come into contact with water. Corrosion of metals in the cooling system is directly related to the amount of scale and biofilm present in the system. Other factors that increase metal corrosion include the use of corrosive biocides and high conductivity due to low bleed rate in cooling towers.

Corrosion rates are measured by placing small test coupons of metal of known weight into the flowing water for a set period, usually 90 days. After the end of the test period the metal coupons are removed, cleaned and weighed again to see how much metal is lost. The corrosion rate is reported in mils per year (MPY). An increasingly popular way to monitor corrosion is by use of an electronic device called a Corrat®.

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## Water Issue Control Methods

The normal problems associated with using water as a heat transfer media must be controlled somehow if one is to enjoy water's energy saving benefits.

### Traditional Chemical Water Treatment

For years the only real option to control scale, bacteria and corrosion was to inject several different chemicals into the water. Chemical control methods can work well if properly applied. Even so, they represent a recurring expense and introduce their own set of additional problems. While by no means a complete listing, the chemical groups presented below represent some common approaches.

#### Scale Control Methods

- **Reducing pH** by direct feeding of sulfuric acid will help prevent scale from forming as well as help the action of some common biocides such as chlorine. The big problems are related to personnel safety and possible damage to the system due to improper mixing with water. This system of control requires very precise control and adjustment.
- **Polyphosphates** tend to retard the formation of calcium carbonate crystals by attaching to microcrystal growth sites. In addition to stabilizing hardness by retarding crystal growth, they inhibit corrosion by deposition of thin films on metal surfaces. The problem with this program is that acid addition is required to maintain the pH at 6.0 to 7.4.

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- **Chelants** are typically organic chemicals that incorporate metal ions within their molecular structure. In this way the chelants effectively tie-up metals like calcium and deactivate them so scales cannot form. Chelants that form water-soluble complexes with metal ions are called sequestrants.
- **Phosphonates, Polymers, Copolymers and Terpolymers** are complex organic molecules that exhibit various deposit control characteristics. They can serve as dispersants (preventing small particles and crystals from settling down onto surfaces), sequestrants, or crystal modifiers (distort and limit the size of crystal growth). Almost all polymers exhibit more than one effect.

### Corrosion Control Methods

- **Fatty Amines** are film-forming inhibitors and can help to inhibit growth of bacteria.
- **Aromatic Azoles** are specific inhibitors for copper and copper alloys where they are adsorbed onto the metal surface. The use of chlorine or bromine products for bacteria control degrades the effectiveness of these compounds.
- **Molybdate** acts as an anodic inhibitor in the presence of oxygen and forms a protective film on the metal surface. Molybdate is very widely used as a replacement for the very effective, but very toxic chromates that can no longer be used in the United States. Unfortunately, molybdenum is increasingly expensive and has received much negative environmental press lately.
- **Nitrite** is a good anodic inhibitor, but it requires a large concentration to be effective. It is subject to oxidation and microbiological attack, so it is most often used only in closed loop systems. To be effective the closed loop will need to be cleaned before treatment. Steps must be taken to prevent oxygen from entering the system and a biocide must be used.
- **Silicates** have been used for over 70 years to treat potable water systems. These silicates are anodic corrosion inhibitors that pose no health risks or environmental concerns.
- **Zinc** can be used if added to many of the scale inhibitors, especially polyphosphates, to provide cathodic protection by forming a protective gelatinous precipitate of zinc hydroxide. To be effective, tower pH needs to be controlled with acid additions to pH 6.0 to 7.4. Higher pH can result in zinc precipitation. Lately there is increasing negative interest in the amount of zinc found in water discharge streams.

### Bacteria Control Methods

- **Oxidizing Biocides** irreversibly oxidize protein groups, resulting in loss of normal enzyme activity and death. The problem with these chemicals is their corrosive nature. Typical oxidizing biocides include chlorine, sodium hypochlorite, bromine, hydrogen peroxide and ozone.
- **Non-oxidizing Biocides** are also available such as isothiazolin, dibromonitripropionamide (DBNPA) and quaternary amines. They are typically very toxic. They need frequent rotation to prevent bacterial resistance.

**Non-oxidizing Biocides** are also available. They are very toxic and must be rotated frequently to prevent biological resistance. They include, isothiazolin, dibromonitripropionamide (DBNPA) and quaternary amines (they tend to foam).

- **Bacteria Control Issues**
  - Established biofilm and algae are very difficult to control with any biocide.
  - Most biocides are very corrosive to metals.

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- Many water treatment chemicals serve as food sources for microbes. These include phosphate corrosion inhibitors, organic polymers as scale inhibitors, dispersants, surfactants and ammonia containing compounds such as copper corrosion inhibitors.

### Traditional Chemical Water Treatment Issues

There are many issues the end user must address if a chemical treatment system is used to control scale, bacteria, and corrosion.

- Recurring cost - the chemical program will require a significant monthly expense for the life of the system.
- Material handling - drums of chemicals must be delivered to the site and positioned near the injection equipment.
- Equipment maintenance - metering pumps must be used to inject the chemicals into the water loop. These pumps are notorious for unexpected failure, requiring disassembly for cleaning and repair. Of course, when a pump fails, no chemicals are injected for some period of time, compromising the effectiveness of the chemical control method.
- Disposal - the drums must be disposed. Some of the chemicals are corrosive and toxic, requiring special disposal procedures.
- Water changes - the supply water chemistry can have large variations based on varying municipal sources, seasons, etc. The chemical treatment program should be adjusted accordingly. Unfortunately, no notification is supplied to the end user that the water has changed. The result is a compromised treatment method.
- Record keeping - because of the corrosive and toxic nature of many of the chemicals, record keeping and reporting is required.
- Operation - between monthly or bi-monthly visits from the chemical supplier, the operator must monitor the treatment and make adjustments. This can be difficult for the end user because of training difficulties and personnel rotation.

Chemical treatment programs can be very effective. Unfortunately, because of these issues, many programs are not. This results in a water cooling loop that is out of control. Due to lack of proper treatment, many loops experience scale formation, high bacteria levels, and unacceptable corrosion rates.

## **Wave™ Physical Water Treatment**

The Wave™ represents the most advanced physical water treatment system available. It is the result of continued research to better understand the science and practice of physical water treatment. There are many physical water treatment devices on the market today. Some work quite well, while others seem to work some of the time and still others are outright fraudulent. In nearly all cases the explanations given for how these systems work are not supported by actual science or true research. This misinformation has been the cause of industry mistrust and has led manufacturers of these devices to misapply their products.

The following information is a factual accounting of how the Wave™ can be of benefit in controlling scale, bacteria and corrosion in cooling water systems. Although the Wave™ is effective in controlling many different mineral scales, calcium carbonate scales are the most common and we will confine our discussion to these. Other scales are controlled by similar reactions or by co-precipitation onto calcium carbonate seed crystals.

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### Understanding Calcium Carbonate

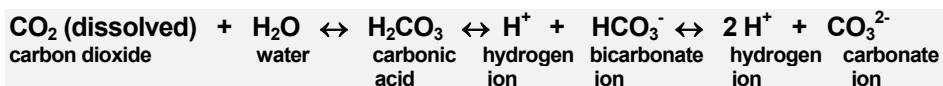
Calcium carbonate is found in nature as limestone, marble and sea shells. Calcium carbonate is largely responsible for the formation of pipe scale. In order to fully understand how the Wave™ can control calcium carbonate scale, one must first have a basic understanding of how calcium carbonate behaves in water. Calcium carbonate (CaCO<sub>3</sub>) is an inverse solubility salt, meaning that less of it will dissolve in hot water than in cold water. This is not what one would normally expect to see when dissolving something in water.

Take table salt (sodium chloride – NaCl) and dissolve as much as you can in cold water. This is now called a saturated salt solution. Now heat that same water over the stove and you will be able to dissolve much more salt. If one now takes the hot, saturated salt solution and cools it on ice, the solution will first become supersaturated and then one will see a large number of small salt crystals forming and falling out of solution (this process is called precipitation).

The inverse solubility of calcium carbonate is what makes it most troublesome. The calcium carbonate will precipitate and scale the warmest spots in the system where heat transfer is taking place. Problems occurring with scaling of tubing, pipes, boilers, coils, cooling towers, heat exchangers, or wherever industry is forced to use heated hard water, cost billions of dollars every year in excess energy usage.

### The Carbon Dioxide Key

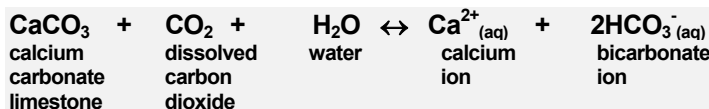
Calcium carbonate is, for all practical purposes, insoluble (does not dissolve) in pure water. If that is the case, how can we have hard water with over 171 ppm (10 grains per gallon) calcium carbonate? The secret lays in the role carbon dioxide gas (CO<sub>2</sub>) plays. Some of the carbon dioxide that is in the air dissolves into the water that falls as rain. This dissolved carbon dioxide makes a very unstable acid called carbonic acid (the same acid found in carbonated water and soft drinks).



NOTE: Double arrows {↔} indicate the reaction can go in either direction.

Carbonic acid instantly dissociates in water to form the negative bicarbonate (HCO<sub>3</sub><sup>-</sup>) and carbonate ions (CO<sub>3</sub><sup>2-</sup>). The forming of carbonic acid when carbon dioxide in the air dissolves in water is the key to dissolving calcium carbonate. It is also the key to why water solutions of calcium carbonate will cause scale to form when heated instead of dissolving additional calcium carbonate. In summary, the combination of limestone, water and carbon dioxide results in significant quantities of calcium ions in solution.

The complex process of dissolving of calcium carbonate in limestone is summarized in the simplified reaction shown below.



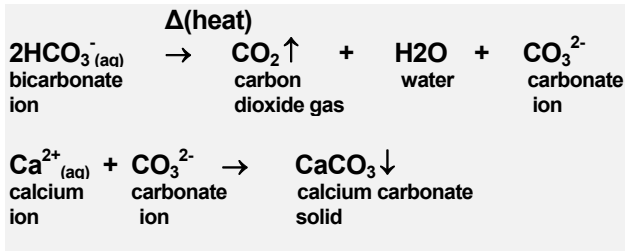
While calcium carbonate is insoluble, calcium associated with the bicarbonate ion is extremely soluble. The hydrogen ions (H<sup>+</sup>) produced by dissolving carbon dioxide react with the carbonate of calcium carbonate forming the very soluble bicarbonate ion and thus the limestone dissolves. Because this reaction can be easily reversed, the dissolved limestone can be deposited in other places as scale or cave deposits.

### Bicarbonate Ion Decomposition

The bicarbonate ion is destroyed by heat. Heat causes increased molecular agitation and provides increased chances for two bicarbonate ions to react releasing carbon dioxide gas; water and forming the

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carbonate ion (see equations below). The carbonate ion will immediately combine with any calcium ions present to form solid calcium carbonate. This is why scale forms easiest on heated surfaces and in hot water pipes.



### Scale Control

#### Electrically Generated Seed Crystals

Another way to cause the same decomposition of bicarbonate and form solid calcium carbonate is to use electrical energy instead of heat energy. As in the case of heat, an electrical field can agitate the bicarbonate ions increasing the likelihood of reacting as illustrated above. Because the amount of electrical energy required to move all the ions flowing in a water filled pipe is so huge, it is not practical to treat 100% of the water. When an alternating electrical field is applied to a section of pipe, small microscopic imperfections in the pipe surface will concentrate the electrical energy. These small points of localized high energy directly cause the chemical reactions to occur. The result is that microscopic seed crystals are formed in the flowing water instead of directly on a hot surface as scale. The seed crystals do not attach to the areas of localized high energy, because, unlike the case of a hot surface, by the time the seed crystal is formed the energy is no longer present to attract more ions to continue the process.

#### Crystal Seeding Prevents Scale Formation

The microscopic seed crystals formed by the Wave™'s electrical fields flow with the water throughout the cooling system. As the seed crystals enter areas of heat or high pH where calcium carbonate will normally form scale, the precipitating calcium carbonate will preferentially attach itself to the existing seed crystals instead. In this way the seed crystals grow larger and start to settle in areas of low flow, such as the tower basin, where they can be swept up and removed during normal tower cleaning or with a bypass filtration system.

#### Removal of Existing Scale

Existing scale is removed by three processes. First, when the bicarbonate ion is decomposed by the intense localized electric fields produced by the Wave™, microscopic bubbles of carbon dioxide gas are transported downstream along with the seed crystals produced. Some of the microscopic bubbles will come in contact with existing scale and react with it to form the very soluble calcium bicarbonate.

Second, there is much scale held in place in a matrix of biofilm within cooling tower fill. The Wave™ is very effective at destroying any biofilm present. When the underlying matrix is removed, the scale falls out of the fill in large pieces.

Third, in heat exchangers scale normally spreads by making use of cracks that are formed during normal thermal cycling. The scale is not flexible, so it cracks when the underlying metal expands or contracts. The cracks normally fill in first because the freshly exposed metal surfaces are hotter than the surrounding scaled surfaces. By providing fresh seed crystals the Wave™ will effectively stop the filling in of the hot spots, and the scale will soon start coming off the tube surfaces as flakes.

### Bacteria Control

Several complex processes account for the Wave™'s ability to successfully control bacteria populations in cooling water.

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### Flocculation & Enhanced Filtration

The Wave™ signal can neutralize some of the static surface charge that naturally forms on all small particles including bacteria that suspended in the water. This means that the small particles will start to stick together and form larger aggregates that will fall to the bottom of the tower basin or be trapped in a bypass filter system. Many bacteria are effectively entombed by the particles and crystals surrounding them and are thus prevented from reproducing and adding to the bacteria population.

### Electroporation

Bacteria exposed to a very intense electrical field will develop small holes in the cell wall. This phenomenon is called “electroporation”. The small holes allow too much oxygen to enter the cell, and thus kill it. The Wave™ provides the small localized areas of intense electrical field that will kill the bacteria that come near enough.

### Biocide Production

Tests of Wave™ treated water indicate there is a definite residual treatment effect very much like that observed when biocides are used. There is also a remarkable destruction of existing biofilms present. While the mechanism involve is not yet fully understood, there is evidence to suggest the possible generation of small amounts of hydrogen peroxide in the water by reacting dissolved oxygen with water. Ongoing research will help to understand this process better.

### Biofilm Reduction

When the overall bacteria population floating in the water can be kept below the quorum that is required to form or sustain a biofilm, the biofilm will dislodge and disperse. Even though biofilm is very resistant to normal biocide attack, the Wave™ is effective at removing existing biofilms and preventing their return.

## Corrosion Control

The Wave™ controls corrosion more by elimination of a corrosive environment than by any direct means.

### Natural Corrosion Inhibitor

By allowing a cooling tower to operate above the normal saturation point for calcium carbonate with the Wave™, we make use of the calcium as a natural corrosion inhibitor. If the tower is operated at low cycles of concentration below the calcium carbonate saturation point the corrosion inhibiting advantage is lost.

### Microbial Induced Corrosion (MIC) Control

Microbial induced corrosion accounts for a good deal of system corrosion issues. The bacteria present form biofilms that can reduce oxygen levels near the metal surface, causing oxygen pitting or under deposit corrosion to occur. Also, sulfate reducing bacteria produce sulfuric acid as a waste product that can very quickly corrode metal surfaces. The Wave™ controls all types of damaging biological activity.

### Elimination of Large Amounts of Corrosive Biocides

The Wave™ eliminates the use of large amounts of very corrosive and toxic biocides. This provides a much safer environment for system metals.

## Advantages of Wave™ Water Treatment Systems

In summation, we wish to present a listing of some of the many advantages to using the Wave™ electronic water treatment system instead of normal chemical based systems:

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- Lends itself better to remote monitoring
- Requires less frequent inspections
- Less on-site chemical analysis required
- No MSDS sheets and hazardous waste paperwork to maintain
- No chemical movement or storage requirements (especially nice for roof top installations)
- No spills of hazardous materials to report
- Less chance to injure employees or guests
- No complex injection pumps to maintain
- Typically better control of bacteria without corrosion and environmental issues
- Can provide a LEED credit for innovative technology by elimination of chemicals released into the environment when water is bled from the system
- Provides a cost effective solution to water treatment that results in a significant payback
- Water can be reused for lawn watering
- Reduction in water disposal costs

The Wave™ provides the strongest signals of any such physical water treatment device currently marketed. This means that more localized areas of high energy will be available for inducing chemical reactions and killing bacteria. The Wave™ is undergoing continual laboratory testing and analysis to provide the best non-chemical water treatment system available. Griswold Water Systems is dedicated to the advancement of the science and technology of physical water treatment systems.