

ALTERNATIVES TO CHLORINE FOR CLEANING COOLING TOWERS

Summary

The new amendments to ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality*, require a minimum separation distance between cooling towers and outdoor air intakes or doors and windows that are a part of a natural ventilation design. However this minimum distance does not necessarily provide protection to building occupants from exposure to cooling tower contaminants. These contaminants may be either bacteria from an infection in the cooling tower sump or cleaning chemicals, generally chlorine, intended to protect against an infection. It has been our experience that attempting to provide such protection by adequate dilution of the cooling tower exhaust before entering an air intake is difficult, if not impossible. A better approach appears to be the use of alternatives to chlorine for maintaining cooling tower health.

Introduction

The new amendments to ASHRAE Standard 62-2001, *Ventilation for Acceptable Indoor Air Quality*, require a minimum separation distance between cooling towers and outdoor air intakes or doors and windows that are a part of a natural ventilation design (Section 5.4 and Table 5.2 as amended August 5, 2004). The required minimum distance between the cooling tower exhaust and the air intake is 25 feet and between the cooling tower sump and the air intake is 15 feet. It appears that this assumes the air intake is located at the same level as the cooling tower, such as on a common roof.

The amount of dilution that actually occurs between the cooling tower and the air intake will be highly dependent on the upward velocity of the cooling tower exhaust and the horizontal velocity of the ambient wind. The amount of upward velocity will depend on the load on the cooling tower at a given time. The theoretical amount of dilution can be quickly calculated from meteorological dispersion equations for simple situations. For more complex geometries, especially with buildings and obstructions near the cooling tower-air intake pair, or for a source on one building and a receptor on another, it may be necessary to utilize wind tunnel or computational fluid dynamics (CFD) modeling to determine the expected dilution over the intervening distance.

A thorough discussion of cooling towers as a source of *legionella*, or Legionnaires' Disease, as it has become popularly known, is provided in the ASHRAE Guideline 12-2000, *Minimizing the Risk of Legionellosis Associated with Building Water Systems*, along with a detailed discussion of preventive measures. The guideline is careful to point out that the problem goes beyond

cooling towers to include humidifiers, whirlpool spas and hot tubs, architectural fountains and waterfalls, evaporative coolers, and even metal working fluids systems.

Bacterial infection in cooling towers

The primary concern with cooling tower exhaust has been the mist in the cooling tower exhaust. Mist drift from cooling towers has been implicated as a source of the infectious proteobacteria *legionella pneumophila*. The conditions in cooling towers can be ideal for the growth of *legionella*, which is present in low concentrations in most water supply systems. The conditions which promote growth of the bacteria are

- a) water temperatures between 95 and 115 degrees F
- b) sediment and food sources in the water which support the growth of algae, etc.
- c) the presence of l-cysteine-HCl and iron salts.

Legionella belongs to an unusual group of bacteria with special properties that can defeat the respiratory disease response system, a group which includes tuberculosis and salmonella. *Legionella* is widely distributed and occurs in five different varieties. Infections commonly appear with only two of the forms, one occurring relatively infrequently but manifesting as a mild respiratory disease in approximately 95% of those exposed and the other a common and more troublesome form that only matures in 2 to 5% of those exposed. The milder form causes flu-like symptoms that pass in less than a week. The other results in severe symptoms, often requires hospitalization and is fatal in about 10% of the cases.

In the best known cases of disease outbreak (a American Legion convention in Philadelphia and the Oakland County Health Department in Pontiac, Michigan) the building air intakes were close to the infected cooling tower. However even with significant separation it is judicious to determine the likelihood of cross-contamination in order chose relative locations that will minimize the opportunity for infection.

Because a cooling tower uses sprays of water to cool the working liquid, the exhaust air from a cooling tower contains fine droplets of water, called mist, that can drift with the exhaust air away from the cooling tower in a plume. If the cooling tower water has developed a *legionella* growth, the mist will contain the bacteria. The mist will evaporate quickly in warm dry conditions, but may remain as droplets for quite a distance in humid conditions. Even when dried, *legionella* can retain its infective capability.

Though growths of the bacteria can be significantly suppressed with proper cooling tower maintenance, there is always a risk of growth, particularly at the times of the year when the greatest demands are being placed on the towers. The Pacific Northwest's humid climate promotes longer transport of the mist drift exhaust through the atmosphere. Since very large volumes of air pass through cooling towers, the plume from a tower can be quite large, even though only a portion of it may contain visible mist.

The degree of dilution of the cooling tower plume with ambient air needed to reduce the risk of *legionella pneumophila* causing Legionnaire's disease to acceptable levels is not known. It is highly dependent on the temperature, humidity, downwind distance, and concentration of the bacteria in the cooling tower itself. The bacteria dies after enough exposure to air, so only a small fraction of the bacteria will survive long on a warm dry day as the cooling tower droplets are quickly evaporated. According to the Centers for Disease Control, on cooler moist days the bacteria may survive up to 1,600-5,000 feet from the source.

Prevention of cooling tower bacterial infection

Several design elements are identified in the ASHRAE Guideline as important to the reduction of infection opportunity in cooling towers. The amount of drift mist can be reduced by newer, state-of-the-art inertial impingement mist eliminators. However, even with a mist eliminator a significant amount of mist drift will still be present in the plume. Reducing the supply of nutrients by filtration of the intake air to prevent dirt, leaves and other debris from reaching the sump is equally important in controlling the scale and corrosion that allows biofilms to develop. Siting the tower away from kitchen exhausts, and their potential grease contamination, is also mentioned.

It is not practically possible to achieve sufficient dilutions between a cooling tower and all potential sensitive receptors to provide adequate protection under all wind conditions. The test must be, is this the best practical location, with the lowest potential exposure, given all aspects of the project? For most projects, the expected dilutions at sensitive receptors will be large, in excess of 5,000 to 10,000, for the most common wind condition and receptor combinations but the expected dilutions may be quite low, less than 100, for some wind condition and receptor combinations. Thus an aggressive maintenance program is considered the first line of defense for reduction of concerns from cooling tower mists.

A very large English study found about 6% of cooling towers infected with *legionella*. Another study found about half with some detectable *legionella* and about 3% infected at a significant level. The Association of Water Technologies, a water treatment trade group, recommends (<http://www.awt.org/new.htm>) ongoing biocide and biodispersant treatment for cooling towers, with the latter necessary to disrupt the biofilms where the *legionella* are protected from the biocides intended to control them. They also provide design guidelines for cooling towers and cooling tower locations. Their maintenance recommendations are for 0.5 up to 2 ppm of free halogens in the cooling tower water for ongoing control and for shock cleaning for annual pre-season maintenance. During shock cleaning of the cooling towers or under conditions which require higher than normal concentrations of the maintenance chemicals, chlorine, if used, may be present in the cooling tower water at up to 10 parts per million (ppm) and methyl bromide, if used, at up to 30 ppm.

While proper maintenance can reduce the risk of *legionella*, the cooling tower exhaust will remain a concern due to the chemical additives used to control bacterial growth. A wide variety of chemical systems are used. The most widely used, chlorine and methyl bromide, can be toxic to humans as well as bacteria. To calculate the equilibrium concentration of the chemical present

in the cooling tower water and the amount released into the air exhausted from the tower it is necessary to make a calculation using the Henry's Law coefficient specific to the chemical mixture in the cooling tower water. This chemical relationship is well documented and easily used to make this calculation.

However, not only are there several chemical combinations used for cleaning cooling towers, there is also a range of Henry's Law coefficient measurements in the chemistry literature. For example, if the chemical used in cleaning is sodium hypochlorite, the system is hypochlorous acid (HClO) and the coefficient ranges from 300 to 900 moles/liter/atm. If the chemical used is chlorine gas (Cl₂) the coefficient ranges between 0.06 and 0.09 moles/liter/atm. If the chemical used is hydrochloric acid (HCl) the value ranges from 1.1 to 2,500 moles/liter/atm. Chlorine dioxide (ClO₂), a chemical popular in the pulp and paper industry, has a coefficient ranging from 0.85 to 1.0 moles/liter/atm.

Depending on the choice of system and coefficient the estimated chlorine in the air will vary over a wide range. Choosing a value of 6 moles/liter/atm and comparing the resulting diluted exhaust concentration to an adjusted Acceptable Source Impact Level (ASIL, a Washington air toxics regulations air quality concentration intended to protect sensitive individuals, adjusted to reflect the shorter time frame of expected exposures), the cooling tower plume should be diluted at least 5000 times at a receiving air intake to reduce the concentration in the uptake air sufficiently to minimize adverse exposures among sensitive individuals. It is important to note that if the action levels of industrial hygiene exposure standards (which were mostly developed during a time when the dominant industrial labor force was composed of young males) are utilized instead of the ASILs, the necessary dilutions are reduced by about a factor of 150, which would calculate out to 50 dilutions to protect a worker.

The obvious question arises, is 10 ppm chlorine in the sump water the only alternative to avoiding high bacterial concentrations in the sump water? This report addresses that question with a review of several alternatives to the use of chlorine as a disinfectant. Following a description of the CDC advice on cooling towers, a summary table is attached which provides data on chlorine and six alternatives to chlorine.

CDC Advisory

The Centers for Disease Control *Guidelines for Environmental Infection Control in Health-Care Facilities* (at www.cdc.gov/ncidod/hip/enviro/Enviro_guide_03.pdf) recommend:

“Implement infection-control procedures for operational cooling towers. . .

- d) Install drift eliminators.
- e) Use an effective EPA-registered biocide on a regular basis.
- f) Maintain towers according to manufacturers' recommendations, and keep detailed maintenance and infection control records, including environmental test results from legionellosis outbreak investigations.”

The CDC report also provides detailed recommendations for pre-season cooling tower cleaning procedures (shock cleaning). First, they advise shutting off the cooling tower fans and closing all building air-intake vents within 100 feet of the cooling tower. Then, they advise

“Add fast-release, chlorine-containing disinfectant . . . Examples of disinfectants include sodium hypochlorite (NaOCl) or calcium hypochlorite (Ca[OCl]₂), calculated to achieve initial free residual chlorine (FRC) of 50 mg/L [ppm]. . . maintain the FRC at >10 mg/L [ppm] for 24 hours . . . thoroughly clean all CT/EC [cooling tower/evaporative cooler] water contact areas . . . Fill the system with water and add chlorine to achieve an FRC of 10 mg/L [ppm] . . . flush the entire system . . . The CT/EC may be put back into service using an effective water-treatment program.”

While the use of chlorine at 10 ppm is suggested as a shock treatment, as an on-going water treatment they comment that some facilities maintain levels of “1-2 mg/L (1-2 ppm)” and they offer the following advice about alternatives:

“Alternative methods for controlling and eradicating legionellae in water systems (e.g., treating water with chlorine dioxide, heavy metal ions [i.e., copper/silver ions], ozone and UV light) have limited the growth of legionellae under laboratory and operating conditions. Further studies on the long-term efficacy of these treatments are needed before these methods can be considered standard applications.

“Renewed interest in the use of chloramines stems from concerns about adverse health effects associated with disinfectants and disinfection by-products. Monochloramine usagae minimizes the formation of disinfection by-products, including trihalomethanes and haloacetic acids. Monochloramine . . . can penetrate biofilms more effectively than free chlorine. However, monochloramine use is limited to municipal water treatment plants and is currently not available to health-care facilities as a supplemental water-treatment approach. . .”

Disinfectants and Disinfection Systems

Chlorine is the traditional disinfectant used most widely in cooling towers, often through application of sodium hypochlorite but occasionally with gaseous chlorine or other forms. Chloramines and chlorine dioxide are becoming more widely used in order to avoid some of the worker and public exposure issues. When used according to recommendations chlorine, chlorine dioxide and chloramines are considered effective although none effectively control biofilms that have become established. Occasional high concentration applications (shock cleaning) are necessary to disrupt the biofilms. Chlorine is somewhat aggressive and does result in some corrosion in the piping and cooling tower equipment. This alone can contribute to scale formation in the cooling tower water system. Excellent, detailed instructions for maintaining a chlorine-based control system are given in *Legionella Control in Health Care Facilities* (HC Information Resources, 1996). This same book reports the costs associated with a chlorination system for the potable water system for a 940 bed hospital as \$130,280 first cost, \$17,800 annual operating cost and \$84,000 for periodic repairs and consultant costs over a 10 year period.

A system called mixed oxidants generates chlorine and bromine on site from a salt solution. This system produces Br:Cl in a 2:1 ratio. Bromine is promoted as being more chemically available in alkaline pH systems, which is typical of cooling tower water, and forming fewer undesirable halogenated organic byproducts than chlorine. A typical system is ElectroBrom, manufactured by ProChemTech International.

A wide variety of other biocides are available. The biocides recommended, rather indirectly, by OSHA are fentichlor [2,2'-thiobis (4-chlorophenol)] and bromo-chloro-dimethyl-hydatoin (BCD) which have been shown to be effective at 300 ppm. Quaternary ammonium compounds, which are widely used in cooling towers, are said by OSHA not to be effective at controlling *legionella*.

Some testing of biocides has been contradictory, with one study showing a particular compound to be effective and another showing it to be entirely ineffective. Even calcium hypochlorite has been found to be ineffective in some studies. Some biocides are effective against *legionella* but not against algae and therefore allow biofilms to develop. Some biocides have been found to be effective at the recommended dosage but not at a more dilute dosage, as will develop over a few days as blow down depletes the cooling tower sump and make up water is added. Others are effective down to less than one percent of the recommended dosage. One study found tributyltin oxide (TBTO) to be a promising constituent of biocides effective against both *legionella* and algae but could not give unqualified support to use of 11 other widely used biocides. (TBTO is so toxic to marine organisms that its use is controversial.) In that study, biocides containing chlorophenates and thiocarbamates were particularly noted as lacking in persistence with dilution. A widely used cooling tower biocide based on a mix of isothiazolin compounds was also found to be ineffective at diluted concentrations.

A **copper-silver ionization** system releases positively charged copper and silver ions into the water from electrodes suspended in the water. The copper and silver ions bind to negatively charged sites on microorganisms, killing them. Legionella are controlled at concentrations of 0.25 to 0.4 ppm for copper and 0.04 for silver. This system is highly effective and has no adverse effects. It is a well-established disinfection approach, dating back to the late mediaeval period, where the plumbing in some monasteries was made of a copper-silver alloy. Both copper and silver at these concentrations are well below the U.S. EPA drinking water standards.

A typical example of these systems are the products of LiquiTech (www.liquitech.net/s_specs_2.asp). LiquiTech generally provides its equipment on a lease basis which includes maintenance. They have quoted a cost of approximately \$1,700 per month for the model system used for this report.

Ozone acts much like chlorine, as a direct chemical oxidant that attacks and kills bacteria and disrupts the structure of biofilm layers. It is normally highly successful at controlling bacteria at levels of 1 to 2 ppm ozone. It is more aggressive than chlorine and at higher concentrations will corrode galvanized piping and equipment. At the low concentrations used there is very little corrosive damage, especially when the water is alkaline. CPVC and 316 stainless steel will not experience significant damage even at high ozone concentrations.

Unlike chlorine, there are no adverse byproducts or air emissions in the cooling tower exit flow when ozone is used. The ozone either oxidizes compounds in the water or neutralizes and is released from the water as oxygen. Ozone systems have been reported to encourage formation of a fine-grained scale which precipitates rather than plating to surfaces. This also allows a lower blowdown rate, using less water.

A typical example of these systems are the products of Ozonia NA (www.ozonia.com/pages/ozatsystems.html). The capital cost for the model cooling tower system is estimated by Ozonia at \$87,000, the annual operating cost is estimated at \$1,420 for electricity at \$0.05/kWhr and the annual maintenance budget at less than \$2,500.

Ultra-violet light systems are widely used as an alternative to chlorination in drinking water treatment plants. Ultraviolet light itself acts to kill bacteria in the water, however it must penetrate through the water to be effective. If the water has a high level of suspended solids or if scale buildup occurs at the UV disinfection unit, the UV light will be much less effective because it cannot penetrate into the entire water column. It does not result in any harmful byproducts, cannot damage the piping or cooling tower and has a relatively low cost where electricity rates are reasonable. Low levels of ozone are generated in the water by UV systems operating with more intense levels of UV light.

A typical example of these systems are the products of the Aquafine Corp. (www.aquafineuv.com/PRODUCTS/ProdIdx.htm). The capital cost of a system of the size necessary for the model cooling towers is estimated by Aquafine at less than \$187,000.

Pulsed-power systems (PPS) are relatively recent but are gaining an acceptance. They appear to have demonstrated an ability to maintain low levels of microbiological activity without the use of corrosive chemicals. PPS operating at much higher power levels than cooling tower designs is an FDA-approved method of pasteurization of food products for human consumption.

Although the systems have been shown to work, there is some controversy over how they work. PPS requires a higher hardness than is found in most Pacific Northwest waters. This can be accomplished either by adding calcium carbonate (CaCO_3) or by running the towers for a few days until the suspended solids concentrate to a supersaturated level. It must have a $\text{pH} > 8$ to work. The PPS is said to enhance agglomeration of the CaCO_3 , binding the bacteria inside of a fine powder precipitate. The precipitate does not scale or contribute to scale and is easily removed. It is also claimed that the oscillating electro-magnetic field enlarges the pores in the cell walls of the bacteria, killing them or preventing reproduction. The processes claimed for particle agglomeration and cell wall damage are poorly understood, with physical chemists and biologists unsure that it should work.

In several papers, generally presented at conferences by customers, the PPS was found to yield significantly lower (by a factor of 4 to 100) counts of bacteria colony forming units in the cooling tower sump water, compared to chemical control systems. The resulting levels were generally about 10 times below published guidelines for safe bacterial levels. In almost all studies PPS

were also found to significantly reduce biofilms and scaling. It is necessary to avoid the use of continuous off-line particulate removal as successful operation depends on a relatively high level of suspended solids. Other papers have reported algae and slime growth and corrosion damage in PPS systems.

A study carried out at the University of Washington in 2005 compared the results in three towers equipped with a pulsed-power system and five towers that use conventional chemical controls. The results suggest the pulsed-power system could operate at about 50% higher solids concentration, resulting in significantly less make up water consumption. The potential for calcium carbonate scale seemed to be lower in the pulsed-power towers but the report cautions that silica scale could be a limiting factor with these systems. No comparison was made of biological control by the two alternative control systems.

A typical example of these systems are the Dolphin products of Clearwater Systems (www.clearwater-dolphin.com/). The capital cost of a system of the size necessary for model cooling towers is estimated by Clearwater at \$93,000 and the annual operating and maintenance cost is estimated at \$2,000.

Conclusions

Ozone, copper-silver and pulsed power systems appear to be useful and cost-effective alternatives to chlorine. Attached is a summary table of the various control systems described here. This table is adapted from one prepared by Gregory Bova of Johns Hopkins Hospital Facilities Engineering. (Note that the size of the model system which drove the costs quoted above is different from the model system used for the table below.) Also attached is an appendix with summaries of several papers describing operation of cooling towers with a PPS system and several discussing studies of ozone systems.

Comparison Chart of Water Disinfection Methods							
Item	Chlorine	Chloramine	Chlorine Dioxide	Copper-Silver	Ozonation	Ultraviolet	Pulsed Power
Chemical Utilized	Sodium Hypochlorite	Chloramine (Chlorine & Ammonia)	Chlorine Dioxide (Sodium Chlorite)	Copper & Silver	None	None	None
By-product	Trihalomethane (Thm)	Trihalomethane (Thm) (Far less than Chlorine)	Some chemical decomposition in form of Chlorite and Chlorate	None	Some Bromate (if Bromine is in the water)	Ozone	None
Effective Max pH	7.8 pH	9 pH	10 pH	8 pH	NA	NA	>8.3 pH
Effective Min Hardness	NA	NA	NA	NA	NA	NA	7.5 pH
Impact on Equipment and Systems	Potential corrosion problems	Minimal potential corrosion problems	Minimal potential corrosion problems	Minimal potential deposition of copper on mild steel /Localized corrosion	Potential corrosion problems when water is <7pH	Potential - corrosion problems if high intensity lamps are used	No potential for corrosion

Item	Chlorine	Chloramine	Chlorine Dioxide	Copper-Silver	Ozonation	Ultraviolet	Pulsed Power
Environmental & Health Effects	Produces carcinogenic Thm.	Produces carcinogenic Thm (Less than Chlorine).	None - does not produce Thm and can destroy some Thm.	Copper is acutely toxic to many aquatic species at levels as low as 50 ppb. System operates between 200 - 600 ppb Copper, 10 to 60 ppb Silver.	None - Bromite identified as an animal carcinogen - Effects on humans unknown	None	None
EPA Approved Primary Drinking Water Disinfectant	Yes (Below 4 ppm)	Yes (Below 4 ppm)	Yes (Below 0.8 ppm)	No	No	No	No
Breaks up Biofilm (At Nominal Operating Conditions)	Not below 50 ppm (System operates at 2-3 ppm)	No (System operates at 2-3 ppm)	Yes	Depends on ppm	No	No	Yes
Inhibits Biofilm (At Nominal Operating Conditions)	Minimal	Minimal	Yes	Depends on ppm	No	No	Yes
Short Term Residual Effectiveness	Yes	Yes - Far less than Chlorine	Yes	Yes	Yes until biofilm is re-established	No	No

Item	Chlorine	Chloramine	Chlorine Dioxide	Copper-Silver	Ozonation	Ultraviolet	Pulsed Power
Long Term Residual Effectiveness	No	No	Minimal - Some until biofilm is re-established - None for bulk water	Yes - (long term studies [>4 years] indicate Legionella may develop a tolerance to Silver)	No	No	No
Chlorine Shocking of Water System Required Prior to System Startup (Shocking Effects Bulk Water Only - No Effect on Biofilm)	Yes	Yes	Not Required	Not Required	No for new systems	Yes	No for new systems
Estimated Cost for a 600 gpm System (Not Installed)	\$9,000 (Approx.)	\$9,000 (Approx.)	\$12,000	\$36,000	\$58,000	\$22,500	\$12,500
Estimated Installation Cost	\$5,000 (Approx.)	\$5,000 (Approx.)	\$3,000	\$5,000	\$5,000(Approx.)	\$10,000	\$1,000
Estimated Annual Maintenance Cost	\$8,000	\$8,000	\$16,650 @ 1 Lb Cio2 or \$28,250 @ 2 Lbs Cio2	\$25,250	<\$1,000	\$12,600	\$3,500

APPENDIX - Summaries of selected papers

Pulsed-Power systems.

Pulse-Power Water Treatment Systems for Cooling Towers. Dave Bisbee, CEM, Sacramento Utility District, November 10, 2003

A. Control overview. The main solutes in water are calcium carbonate (CaCO_3), iron, and silica. These solutes become supersaturated in a cooling tower and precipitate from the solution. The natural electrical charge or alignment of these molecules promotes agglomeration on the metal surfaces of the equipment, forming scale.

A “cycle of concentration” is the ratio of the mineral content of the tower water to the mineral content of the make-up water. The average tower ranges from 2 to 4 cycles. Blow-down (addition of make-up water to replenish evaporated stocks and to soften the water) occurs when the water becomes too hard or reaches a critical low level.

The goal for chemically treated towers in bacterial control is to maintain a total count of 20,000 to 50,000 colony forming units per milliliter (CFU/ml). Buildup of scale and slime increases bacterial counts in the reservoir by allowing more suitable areas for colonies to form. Chemical treatment can maintain low levels of bacteria in a tower, but must be switched periodically to maintain adequate control because some chemicals are species specific and resistant colonies can form.

Bromine, Chlorine, and Ozone are oxidizing biocides and the most effective chemical controllers. However, they are very corrosive. Corrosion occurs when the water becomes acidic, so phosphates and silicates usually must be added to the water to offset the acidity of the chemical controllers. A pH of 6.5-9.0 is a recommended range for towers (from Baltimore Air Coil), slightly to moderately alkaline.

B. Pulsepower technology The Dolphin system uses a technique known as “Pulse-power.” Pulse-power systems (PPS) consist of 2 parts: a pulse generator (basically an alternating current transformer), and a reaction chamber (insulated wire coiled around the flow tube: basically an electromagnet). The article claims that the reaction chamber exposes the water to varying electromagnetic energy to alter the electrical charge of the particles. This promotes nucleation. With a higher concentration of nuclei, CaCO_3 crystal growth is favored.

The electromagnetic field lowers the negative electric charge on the surface of particles within the solution, giving the particles a more neutral charge allowing them to coagulate easier.

This theory of pulse-power action is not fully accepted in the scientific community. Electrokinetics of ions in a solution is accepted and is tied closely to the lowering of zeta potential. If zeta potential is lowered to a neutral state, coagulation can occur much easier. Nevertheless, this entire process can still be deemed experimental and not well understood.

C. Bacterial control Pulse power is a FDA-approved technique at pasteurizing fluids such as fruit juices. Microbes are eliminated through exposure to intense electromagnetic radiation. However, the energy is at least 100 times that of the Dolphin. However, the low powered PPS is claimed to still be effective in control of microbes in 2 ways:

- a) Encapsulation: CaCO_3 growth on a nuclei will surround any bacteria which coalesce on the nuclei. The bacteria do not die but cannot reproduce while encapsulated.
- b) Electroporation: continued exposure to EM radiation will damage cell walls. Damaged cells will not be able to replicate.

D. Case study To conclude this paper, a field experiment of 2 239-ton (in cooling) towers was conducted: one using PPS and the other using chemicals. The experiment demonstrates better performance of the PPS tower in microbiological control. The PPS system ran with higher hardness and alkaline conditions. The PPS system was more water efficient and was easier to clean. Corrosion was less of a problem due to the high pH with less variability. Both towers were not analyzed for Legionella bacteria. The specific form of chemical treatment used was not identified.

The towers operated at an average 15 cycles of concentration (the tower water has 15 times the concentration of solute than the source blow-down water). The total bacterial count ranged from 1,000 CFU/ml to 10,000 CFU/ml. The chemically treated tower operated at an average of 5.6 cycles of concentration. It had a high of 1,000,000 CFU/ml and required shock treatment to achieve 1,000 CFU/ml, but plateauing back out at 100,000 CFU/ml.

Chemical vs. Non-chemical Cooling Water Treatments: a Side-by-Side Comparison. Kevin Kitzman, Alcoa. International Water Conference-03-22

This article is a field study of identical cooling towers using different control technologies, including the PPS. The 3 297-ton (tons in cooling) towers in the study were adjacent to each other at a manufacturing plant. The chemical treated tower used non-oxidizing biocides. One tower included a standard PPS, like the Dolphin. The third method was a hydrodynamic cavitation system. This system works by accelerating water at high speeds down a tube. At high speeds, microscopic gas bubbles will form and deform in water. These gas pockets will encourage the aggregation of salts, promoting precipitation.

The study tested the three methods at different cycles of concentration beginning with 3-5 cycles of concentration. About once a month, the cycle of concentration was allowed to get higher and higher (but adjusting the level of conductivity of the water in which blow-down occurs: the more alkaline, the more conductive).

Makeup water alkalinity was steady at 60 mg/l in the beginning of the study and dropped to 44 mg/l by the end.

The study demonstrated that the non-chemical methods better controlled microbiological growth. PPS averaged about 65,000 CFU/ml, the hydro cavitation system averaged 95,500 CFU/ml and the chemical treatment method averaged 270,000 CFU/ml. The chemical treatment varied widely with a high of 8,000,000 CFU/ml and a low of 7 CFU/ml. The study does indicate that the chemical treatment is at a disadvantage in this study due to the lack of a sidestream solids removal device, which would remove some of the scale where bacteria and other organisms flourish: mostly because the biocides can not penetrate some areas of the buildup. This is much less of an issue with the powered systems, where the bacteria are deactivated from encapsulation.

Biological Control in Cooling Towers Treated with Pulsed-Power Systems. Dennis Opheim, Quinnipiac University. John Lane, Clearwater systems. International Water Conference-01-54

Compares three cooling towers in Connecticut: two at an industrial site and one at a skating rink. One of the industrial site cooling towers (tower 1, 100 tons of cooling) used a PPS control. The other, tower 2 (200 tons), used free chlorine control. The third tower (100 tons) used unidentified chemical treatment at a skating rink. Chemical treatment for tower 2 involved the application of free chlorine maintained at 0.3-0.5 ppm with periodic shock treatment. The make-up water had an average alkalinity of 120 ppm CaCO₃ and 13 ppm CaCO₃ for the industrial site and the skating rink respectively. The tower blow-down controller was set to allow 10 cycles of concentration for the towers with PPS and 4 cycles of concentration for the tower with chemical treatment. The industrial towers contained side stream bag filters and the skating tower did not.

The average magnitude of control was 1,000 CFU/ml and was as high as 10,000 CFU/ml using a PPS at the industrial site. An average of 10,000 CFU/ml and a maximum of 100,000 CFU/ml in magnitude occurred in the chemically treated tower. The chemically treated tower was later switched to a PPS system, and the bacterial control improved to that of the other tower using PPS.

Field observations noted that algal mats and biofilms were visible in the chemically treated tower. After PPS installation, the mats and films slowly disappeared.

At the skating rink tower, chemical treatment maintained a 100,000 CFU/mL average concentration of microbes. After installation of PPS at the site, the concentration dipped to an average of about 500 CFU/mL.

Cooling Towers Non-Chemical Water Conditioning at Schick: A Pollution Prevention Study. Connecticut Department of Environmental Protection: dep.state.ct.us/wst/p2/p2cases/cooltower.htm

This article is an independent comparison of the operation of a PPS controlled cooling tower (110-ton cooling) and chemically controlled cooling tower. After installation of the PPS the pH

raised from 7.37 to 8.61. Bacterial counts maintained between 1-17,000 CFU/mL compared to 30,000 to 100,000 CFU/mL in the chemically controlled tower in the same time period.

[Literature arguing against the use of PPS for cooling towers is not as numerous as that which supports it. Only one document was found that strongly disputed the positive claims of the previous papers. The document was a case study performed by a firm that performs chemical treatment of water towers. Overall, this paper has some poor arguments with little scientific backing. The case study illustrated, which demonstrates better performance using chemical treatment, is questionable.]

Case History Report: Water Treatment “Non Chemical Device.” ProChemTech.,
www.prochemtech.com/techpaper/Dolphin2.html

Two pairs of cooling towers exist at a site in Pittsburgh, PA. PPS was installed and operated on the four towers for a year and a half. Upon site visit of the towers, the investigators report that the towers have substantial corrosion, scaling, deposition, and algae growth. Reports show that the towers require frequent manual cleanups to remove the large volume of algae and slime growth. A biological sample reports an average 1,240 CFU/ml of a planktonic plate count and “too numerous to count” using a sessile swab.

The article attempts to debunk the physics behind the Dolphin system. It claims that no charge occurs in the solution, so an electric field can have no effect on the solution. This is not correct as water will contain ions unless it is distilled. Ions are effectively “charged particles” and their alignment and direction of movement (electrokinetics) will be affected if placed in an electromagnetic field. Even non-charged particles such as calcium carbonate will align in the field since the particles are a dipole. But it is not clear how this affects coagulation of the precipitates. Further, coagulation of particles from electrokinetics by lowering the zeta potential of solutes is still rather hypothetical, and not an established scientific fact in the literature.

The towers reportedly have a high pH as expected of 8.1. The total alkalinity as CaCO₃ was about 156 ppm average. The tower did use a Lakos hydrocyclone, which is used to keep concentration cycles low. Despite the alkalinity reported, it is possible that this device was eliminating the larger CaCO₃ seeds from the stream, limiting the effectiveness of the dolphin.

Ozone treatment

Demonstration of Ozone Treatment for Cooling Towers at Thayer Hall, U.S. Military Academy.
Vincent Hock and Robert Hess, US Army Corps of Engineers. Puckorious and Associates,
Evergreen, CO

This paper discusses the success of using ozone treatment to control bacteria in 3 300 ton cooling towers at West Point, NY. Six pounds of ozone per day were injected into the towers leading to a

maximum concentration of 0.09 to 0.1 ppm of ozone in the water. Water from the tower is fed into a mixture chamber which mixes the ozone into the system. After ozone feed began, the cycle of concentration approached 7 after 2 weeks of operation.

Corrosion tests demonstrated that ozone use would be a problem. Corrosion for mild steel was at 5-7 mils per year (mpy), but pitting was excessive. Copper alloys, galvanized steel, and aluminum was also high with rates of 5-7 mpy. Copper/nickel alloy and stainless steel corrosion was low and acceptable.

Biological control analysis found infection levels at 105-106 CFU/ml. This seems quite good, but the paper indicates that 103-104 CFU/ml would be a indicator of good control. The paper indicated that these levels were therefore, too high.

Application of Ozone in Cooling Water Systems. R.J. Strittmatter, Byang and D.A. Johnson: Nalco Chemical Company. Paper presented: National Association of Corrosion Engineers Corrosion 1992 Meeting, Nashville, Tennessee.

This paper is a good comprehensive study of the use of ozone use in cooling towers performed by a firm which supplies ozone for treatment, therefore having a vested interest in the support of ozone for cooling tower treatment. Ozone dosage was based on a target ozone concentration of 0.05 to 0.10 ppm and was about 0.5 lb/day.

The paper claims that ozone tends not to be corrosive when water is alkaline. If the water is neutral or slightly acidic, the ozone increases the rate of corrosion. A comparison of towers with and without ozone control showed that ozone treatment increased corrosion rate significantly at lower cycles of concentration. At high cycles of concentration (~8 coc) the ozone treated tower actually had lower corrosion rates.

Scale formation, which is related to the cycle of concentration, was similar in both treated and non-treated towers. However, this study demonstrated that ozone treatment encouraged the precipitation of calcium carbonate, similar to the PPS treated system. "Sandy" crystalline deposits were evident in treated towers rather than the hard scale buildup typical of non treated towers. Like PPS, the ozone tends to initiate crystal nuclei, encouraging the precipitation of scale.

The study demonstrated "excellent" microbiological control in ozone treated towers. Ozone treated towers maintained counts below 1,000 CFU/ml compared to the counts of 10,000 to 100,000 CFU/ml in the non treated towers.

Ozone for Cooling Tower Systems- An Update and Lessons Learned at the Kennedy Space Center. Daniel Tierney, Space Gateway Support, Kennedy Space Center, Florida.
International Water Conference-02-32

This paper is a good independent review of the use of ozone in cooling towers from a author with a long history of operational experience. It is an objective article which summarizes application experience and “lessons learned” by use of ozone.

The Kennedy Space Center switched six towers to ozone from an alternating biocide program with scale and corrosion inhibitor. Initially huge problems arose from lack of ozone production from the machinery and excessive. The towers in this study were huge (ranging from 3500 to 10,000 tons in cooling).

The study doesn't directly measure microbiological control but demonstrates reasonable levels of scale control and high pH after bugs are worked out of the systems. Therefore, it assumes that control is adequate.

Federal Technology Alert: Ozone Treatment for Cooling Towers. New Technology Demonstration Program, US Department of Energy. August, 1998.

This paper is a sweeping document recommending the use of ozone in cooling towers. It offers many arguments of the economic and control benefits of using ozone and provides two case studies in which ozone has successfully been used in tower control. The first study involves the same towers reviewed at the Kennedy Space Center looked at in a previously reviewed paper. The second case study involves two towers at a Lockheed-Martin plant. Both case studies focus mainly on the economic benefit of using ozone instead of standard chemical treatment. The second case study does report some microbiological control successes.

In the second case study, two moderate sized towers (300 tons of cooling each) were operated with the use of ozone as the controlling technology. In this case, microbiological control went from averaging 1,000,000 CFU/ml with standard chemical control to 1,000 CFU/ml with ozone control. The better control allowed the towers to operated with less blowdown (90% reduction) achieving an alkaline environment. Ozone influence led to precipitate in this saturated environment similar to that witnessed using a PPS. Economic benefit was substantial with the lower blowdown. The document also provides an extensive list of large firms using ozone control in their cooling towers, including many large federal operations.