Ozone Treatment for Cooling Towers

New Energy and Water Saving Technology to Reduce Cooling Tower Operating Costs

Abstract

The use of ozone as a maintenance treatment for cooling towers has good potential for operation and maintenance savings in the Federal sector. A small amount of ozone acts as a powerful biocide that decreases or nearly eliminates the need to remove quantities of water from the cooling tower in order to decrease the concentration of organic and mineral solids in the system. Ozone treatment can also reduce the need for chemical additives added to the cooling tower water.

In a properly installed and operating system, bacterial counts are reduced, with a subsequent minimization of the buildup of biofilm on heat exchanger surfaces. The resulting reduction in energy use, increased cooling tower operating efficiency, and reduced maintenance effort provide cost savings as well as environmental benefit and regulatory compliance with respect to discharge of wastewater from blow down.

Cooling towers associated with chillers for air-conditioning are good candidates for ozone application. Ozone may be a corrosion stimulant rather than an inhibitor, and this can be a factor in some circumstances. Nevertheless, it is easier to combat corrosion in a clean system than in one that is biologically and mineralogically fouled.

This *Federal Technology Alert (FTA)* provides detailed information and procedures that a Federal energy manager needs to evaluate most cooling tower ozone treatment applications. The New Technology Demonstration Program (NDTP) technology selection process and general benefits to the Federal sector are outlined. Ozone treatment, energy savings, and other benefits are explained. Guidelines are provided for appropriate application and installation. Two actual case studies are presented to give the reader a sense of costs and energy savings. Current manufacturers, technology users, and references for further reading are included for prospective users who have specific or highly technical questions not fully addressed in this *FTA*.

About the Technology

Ozone is a molecule consisting of three oxygen atoms and is commonly denoted O_3. Under ambient conditions, ozone is very unstable and as a result has a relatively short half-life of usually less than 10 minutes. Ozone is a powerful biocide and virus deactivant and will oxidize many organic and inorganic substances. These properties have made ozone an effective chemical for water treatment for nearly a century. During the last 20 years, technological improvements have made smaller-scale, stand-alone commercial ozone generators both economically feasible and reliable. Using ozone to treat cooling tower water is a relatively new practice; however, its market share is growing as a result of water and energy savings and environmental benefits relative to traditional chemical treatment processes. Ozone treatment of cooling tower water is not feasible in all situations and hence traditional chemical treatment of cooling tower water is the only alternative.

A cooling tower functions to cool a circulating stream of water (see Figure 1). The tower acts as a heat exchanger by driving ambient air through falling water, causing some of the warmed water to evaporate (evaporation gives off heat--providing cooling), and then circulating cooler water back through whatever equipment needs cooling (such as a chiller condenser). Typically, chemicals such as chlorine and chelating agents are added to cooling tower water to control biological growth (called "biofilm") and inhibit mineral build-up (called "scale"). The control of biofilm and scale is essential in maintaining cooling tower heat transfer efficiency. As the water volume in the tower is reduced through evaporation and drift, the concentration of these chemicals and their byproducts increases. Cooling towers also pick up contaminants from the ambient air. To maintain chemical and contaminant concentrations at a prudent level, water is periodically removed from the system through a process called "blowdown"or "bleed off". The blowdown water and the water lost through evaporation and drift are replaced with fresh "make-up" water (which will also contain minerals and other impurities).

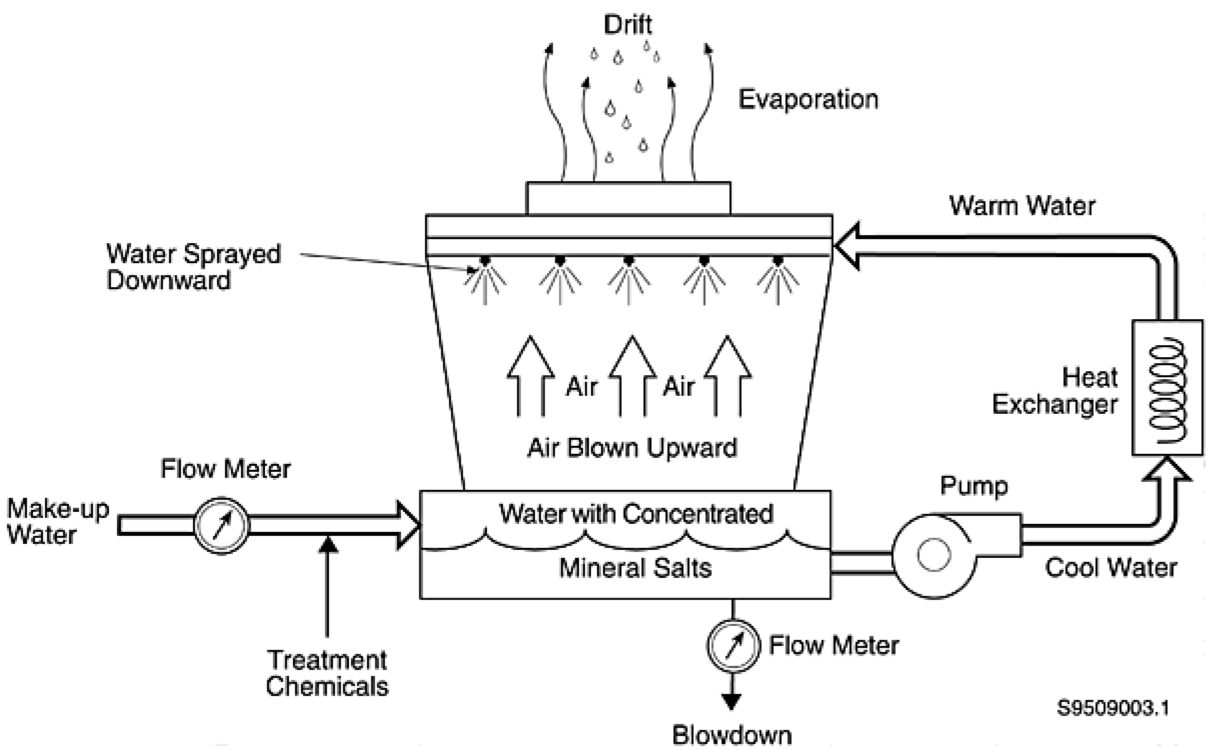

Fig. 1. Typical Cooling Tower Operation

Blow down water must subsequently be discharged to a local wastewater treatment facility or discharged onsite to the environment. The blow down water typically contains little organic material, and the local wastewater treatment facility will charge extra sewage fees for accepting the water. These costs can be quite significant in the overall costs of operating a cooling tower. Discharge of the blow down water to the environment onsite is coming under increasing regulation due to stricter regulation of the contaminants typically found in blow down water. Ozone will dissipate quickly and not be found in the blow down water. This reduces the overall chemical load found in the discharged water, making it easier to comply with regulations.

Most cooling tower ozone treatment systems include the following components: an air dryer, air compressor, water and oil coalescing filters, particle filter, ozone injectors, an ozone generator, and a monitoring/control system. Ambient air is compressed, dried, and then ionized in the generator to produce ozone. Ozone is typically applied to cooling water through a side stream of the circulating tower water as is illustrated in Figure 2.

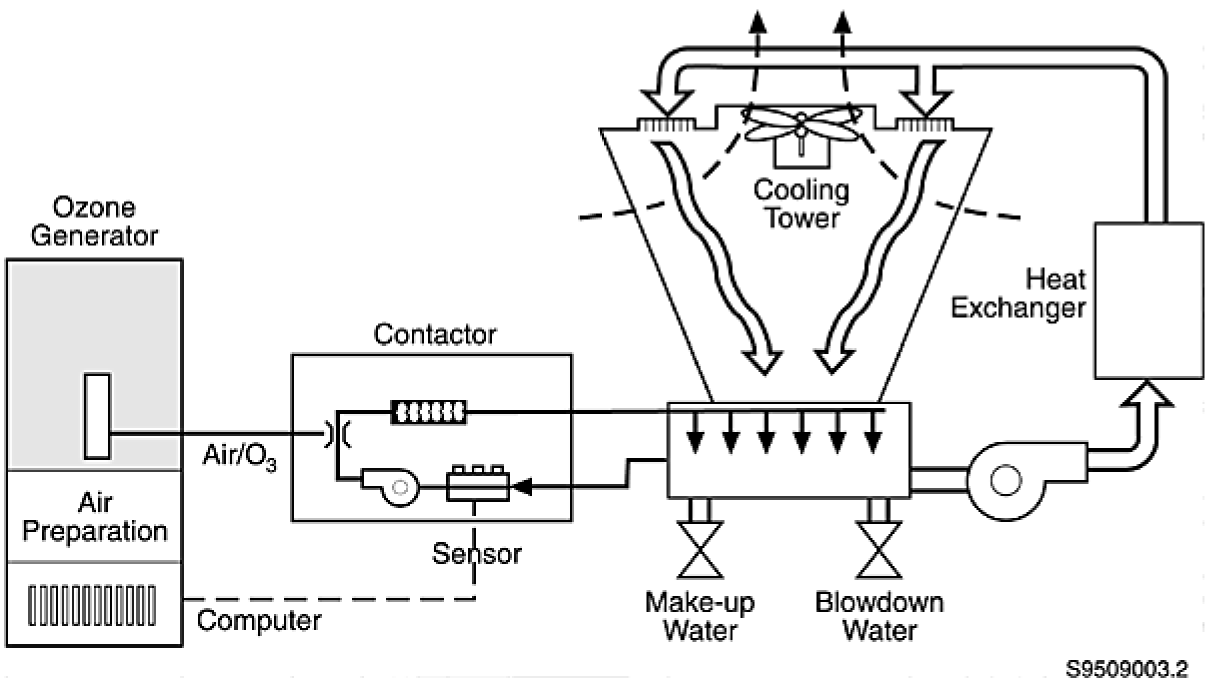

Fig. 2. Process for Ozone Treatment of Cooling Tower Water

Field tests have demonstrated that the use of ozone in place of chemical treatment can reduce the need for blow down, and, in some cases where make-up water and ambient air are relatively clean, can eliminate it. As a result, cost savings accrue from decreased chemical and water use requirements and from a reduction of wastewater volume. There are also environmental benefits as fewer chlorine or chlorinated compounds and other chemicals are discharged.

There is also a belief within the industry (and some evidence) that under certain conditions ozone acts as a descaling agent. The premise is that ozone oxidizes the biofilm that serves as a binding agent adhering scale to heat exchange surfaces. When scale buildup on condenser tubes is reduced, higher heat transfer rates are achieved. Increasing the condenser heat transfer rate will reduce the chiller head pressure, which then allows the chiller to operate more efficiently and consume less energy.

There is a growing number of manufacturers and distributors of ozone equipment in the United States, and the use of this technology is encouraged by several major electric utilities and by electric utility and cooling tower associations. Each new application of ozone for cooling tower water treatment increases understanding of its overall effectiveness and its applicability under differing physical conditions. The technology has had both success and failure.

More information on the criteria for applicability and the potential for the use of this technology in the Federal sector is provided below.

Application Domain

It is estimated that ozone treatment is applied on anywhere from 300 to 1,000 cooling towers in the United States. Most of these towers dissipate heat generated by commercial heating, ventilating, and air-conditioning (HVAC) systems and light industrial processes. The total number of cooling towers requiring chemical treatment in the United States is estimated at between 500,000 and 600,000.

Biological growth, scaling, and corrosion are the main maintenance concerns with these cooling towers. Typical treatment involves the application of chemicals such as chlorine, sulfuric acid, phosphorous, and zinc compounds. Care must be taken in the storage, use, or discharge of these chemicals. Care must be taken to ensure that the proper mixes and proportions of chemicals are used, and to determine the corresponding blow down rates. Excessive application can increase the possibility of corrosion and other undesirable impacts. As traditional chemical water treatments are being restricted because of environmental concerns, ozone is gaining acceptance as a viable biocide alternative.

Cooling tower water is continuously exposed to airborne organic materials, and the buildup of bacteria, algae, fungi, and viruses presents hazards to the tower system and to the health of humans encountering the water. For example, Legionnaire's Disease is caused by the bacterium *Legionella pneumophila* that frequently thrives in cooling tower environments. High levels of bacteria can also lead to an increased risk of microbial influenced corrosion. Certain sulfate-reducing and iron-metabolizing bacteria can destroy iron piping in as little as 9 months. Moreover, a biofilm coating on heat exchanger surfaces reduces heat transfer efficiency. Ozone kills bacteria by rupturing their cell walls, a process to which microorganisms cannot develop immunity. Residual ozone concentrations greater than or equal to 0.4 mg/L have been shown to result in a 100% kill in 2 to 3 minutes for *Pseudomonas fluorescens* (a biofilm producer) in a biofilm, while residual concentrations of as little as 0.1 mg/L will remove 70-80% of the biofilm in a 3-hour exposure. Studies have also shown that ozone concentrations less than 0.1 mg/L will reduce the populations of *Legionella pneumophila* in cooling tower waters by 80%.

Another phenomenon requiring treatment in cooling towers is mineral buildup. Minerals such as calcium and magnesium, which are common dissolved solids in water, are deposited by two different mechanisms, thermal and biological. As the water in a tower evaporates, dissolved solids concentrate in the recirculating water. Biofilms also start to form on the walls and other components of the tower. In essence, the biofilm acts as an adherent for mineral micro-crystals. Over time, deposition of organic and inorganic matter increases scale thickness. Ozone can loosen and remove the scale if the biofilm is present, but if the biofilm is not present the ozone may be ineffective in removing the scale. Biofilm may not be the dominant fraction of scale where the temperature of the heat exchanger is in excess of 135°F. Scale-forming minerals are less soluble at these higher temperatures and can deposit from solution directly onto pipe walls.

One operating concern of a cooling tower is the gradual corrosion of various parts of the tower. Much of the corrosion in cooling towers is associated with bacteria that create conditions favoring microbiologically induced corrosion. When adequate quantities of ozone are injected, control of the microbial population is accomplished. On the other hand, due to its high chemical oxidation potential, ozone can be quite corrosive. However, because a very small amount of ozone performs effectively as a biocide, and because of its very short half-life, the corrosive effects are minimized.

There is also an observed phenomenon of ozone-treated cooling tower water, wherein the pH of the system rises above 8.5 and corrosion protection of the cooling tower components takes place. This phenomenon may also be dependent upon make-up water characteristics such as alkalinity and hardness, so it does not release the operator of the cooling tower from the obligation of making regular corrosion measurements.

Energy and Water Saving Mechanisms

Scale and biological deposits reduce the ability of refrigerant condensers and industrial-process heat-exchangers to transfer heat. By removing and inhibiting biological deposits and scale more effectively than chemical treatment, ozone cooling tower water treatment can improve chiller system performance. Manufacturers claim an average efficiency gain of 10%; case studies range from no improvement in efficiency to a 20% improvement in chiller performance. Energy savings should be estimated for each individual application and based on the actual operating condition of the condenser or heat exchanger and the type of scale present. Further, any projected electrical savings must be weighed against energy consumed by ozone generators and auxiliaries, typically 9 kWh to 14 kWh per pound (0.45 kg) of ozone generated.

Water is lost from a cooling tower in three ways: drift, evaporation, and blow down. Drift occurs when the water droplets become entrained in the discharge air stream and can be controlled through cooling tower design. Evaporation is from air passing through the cooling water and absorbing heat and mass. Blow down is intentional bleed-off (replaced by make-up water) to reduce the concentration of contaminants.

The capacity of a cooling tower is typically measured in tons, the rate at which the tower rejects heat. One ton of cooling is equal to rejecting 12,000 Btu (British thermal units) per hour (3.5 kW). This heat is released through evaporation. The rate of evaporative water loss is about 12 gallons (45.4 L) per minute for every 500 tons (1,750 kW) of cooling tower tonnage. Ozone will not increase or decrease the rate of evaporation.

However, compared to chemical treatment at the allowable dosages, ozone treatment contributes far less to the tower's dissolved solids loading in the circulation water and is therefore more amenable to operation at higher cycles of concentration.

"Cycles of concentration," "number of cycles," or "concentration ratio" are some of the terms used to describe the relationship between the quantity and quality of make-up water and the volume and constituents of the bleed-off. This concentration ratio can be thought of as an indicator of the number of times water is used in the cooling tower before it is discharged, based on a mass balance between dissolved solids entering the system in make-up water and dissolved solids leaving the system in blow down. The higher the cycles of concentration, the lower the blow down.

Blow down water from a cooling tower can be sent to a municipal drain, or it may require onsite pretreatment prior to disposal to a drain. In some cases, blow down may be stored onsite and then retrieved by a disposal service. The savings are a direct function of the costs associated with these three disposal processes and the blow down volume reduction achieved by the ozone system.

If water and sewer services are purchased from a municipal or public utility, reducing blow down and make-up water requirements will trigger a series of resource and cost savings for those municipal utilities. If the site operates its own water treatment and wastewater treatment facilities, reducing blow down and make-up water requirements will allow the facility to realize these benefits directly as follows:

- reduced pumping power to extract water from source wells or reservoir and pump to water treatment facility
- reduced chemical, filtration, and maintenance costs associated with treating and purifying at the water treatment facility
- reduced pumping power for distributing the water from the water treatment facility to the end-user
- reduced pumping power and associated costs to transport wastewater (blowdown) to the sewage treatment plant
- reduced chemical and maintenance costs, and reduced pumping power associated with sewage treatment at the plant
- reduced costs associated with permits allowing the discharge of treated sewer water to a river or stream.

Other Benefits

Besides its potential to reduce water and energy requirements, ozone treatment can reduce or eliminate chemical use, eliminate infectious bacteria, and improve regulatory compliance. Environmental and health benefits occur as potentially harmful molecules are broken down into less toxic byproducts. Properly controlled ozone applications decrease the levels of both bacterial and mineral substances in the waters discharged through blow down or bleed-off.

Chemical treatment costs vary according to the size and chemical requirements of the tower. These costs can be reduced by using ozone as the treatment technology. Case studies indicate that chemical cost savings are a large contributor to the cost-effectiveness of an ozone system.

One manufacturer claims that in normal operation, chiller tubes are usually brushed out once a year, and the tower sump is shoveled once or twice per year. When performing a cost savings evaluation for a potential customer, the manufacturer takes credit for eliminating this maintenance requirement. Although it may not be necessary to brush out the tubes more than once a year, it may still be necessary to shovel the sump for a number of possible reasons. Therefore, it is generally recommended not to accept maintenance and labor savings estimates for a facility without consulting the facility's maintenance personnel. In addition, it is more likely that maintenance savings will come from the reduction in chemical treatment system labor. This savings should be weighed against maintenance requirements of the ozone system, which are reported to be minor.

Finally, with a reduction in biological growth, scale, corrosion, and chemical use, the issue of liability decreases as well. From a human resources perspective, reduced risk to personnel health enhances the working environment and makes a positive public statement.

Variations

Ozone generation is accomplished by passing a high-voltage alternating current (6-20kV) across a dielectric discharge gap through which air is injected (see Figure 3). As air is exposed to the electricity, oxygen molecules disassociate and form single oxygen atoms, some of which combine with other oxygen molecules to form ozone. Different manufacturers have their own variations of components for ozone generators. Two different dielectric configurations exist--flat plates and concentric tubes. Most generators are installed with the tube configuration. Cylindrical configurations offer the easiest maintenance.

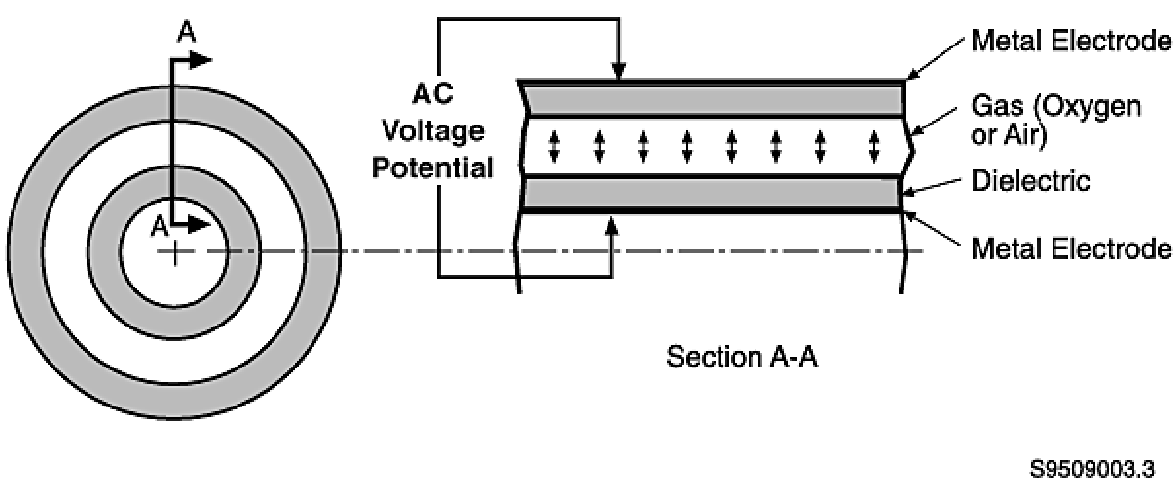

Fig. 3. Dielectric Process for Ozone Generation

Mass transfer of the ozone gas stream to the cooling tower water is usually accomplished through a venturi in a recirculation line connected to the sump of the cooling tower where the temperature of the water is the lowest. Since the solubility of ozone is very temperature-dependent, the point of lowest temperature provides for the maximum amount of ozone to be introduced in solution to the tower. Mass transfer equipment can take other forms: column bubble diffusers, positive pressure injection (U-tube), turbine mixer tank, and packed tower. The counter-current column-bubble contactor is the most efficient and cost-effective but is not always useful in a cooling tower setting because of space constraints. Hence, setups like a venturi followed by an in-line static mixer, or an eductor followed by an in-line static mixer, are common in the installation of an ozone system.

Some ozone treatment equipment vendors propose that the most effective use of ozone is through controlled low doses proportional to the thermal and organic loads of the water. Several factors can influence load, or the oxidation reduction potential (ORP) of the water, including temperature, air quality in the vicinity of the tower, and cooling demands. To provide a proportional quantity of ozone, the ORP must be measured frequently and the ozone generation system must be capable of instant response to changes in ORP. The ORP is a useful criterion because other biocides can accumulate in the tower when blow down is reduced. These biocides include chlorine from the make-up water and bromate species resulting from the ozone oxidation of trace bromine in the make-up water.

Unfortunately, the ORP probe is prone to fouling (usually by a fine layer of calcium carbonate). Maintenance is simple--and it is essential. If the probe is not cleaned, the ozone system is likely to stray from proportional control. The benefit of proportional control and variable ozone generation capability is that only the necessary quantity of ozone is generated; thus, energy consumption costs are minimized, as is the possibility of corrosion from excessive ozone.

Ozone generators create heat and require a cooling system. Some manufacturers indicate that water is the coolant of choice; however, others prescribe cabinet air-conditioning units to keep constant temperatures and reduce air moisture content. Regardless of which system is employed, reliable cooling is essential to preserve the dielectric and to optimize ozone generation.

Federal Sector Potential

The potential cost-effective savings achievable by this technology were estimated as a part of the technology assessment process of the New Technology Demonstration Program (NTDP).

Technology Screening Process

New technologies were solicited for NTDP participation through advertisements in the *Commerce Business Daily* and trade journals, and through direct correspondence. Responses were obtained from manufacturers, utilities, trade associations, research institutes, Federal sites, and other interested parties. Based on these responses, the technologies were evaluated in terms of potential Federal-sector energy savings and procurement, installation, and maintenance costs. They were also categorized as either just coming to market ("unproven" technologies) or as technologies for which field data already exist ("proven" technologies). Note this solicitation process is ongoing and as additional suggestions are reviewed, they are evaluated and become potential NTDP participants.

The energy savings and market potentials of each candidate technology were evaluated using a modified version of the Facility Energy Decision Screening (FEDS) software tool, developed for the Federal Energy Management Program (FEMP), Construction Engineering Research Laboratories (CERL), and the Naval Facilities Engineering Service Center (NFESC) by Pacific Northwest National Laboratory (PNNL) (Dirks and Wrench 1993).

During the solicitation period in which ozone treatment of cooling tower water was suggested, 21 of 54 new energy-saving technologies were assessed using the modified FEDS. Thirty-three were eliminated in the qualitative pre-screening process for various reasons: not ready for production, not truly energy-saving, not applicable to a sufficient fraction of existing facilities, or not U.S. technology. Eighteen of the remaining 21 technologies, including ozone treatment of cooling tower water, were judged life-cycle cost-effective (at one or more federal sites) in terms of installation cost, net present value, and energy savings. In addition, significant environmental savings from use of many of these technologies are likely through reductions of CO_2, NO_x and SO_2 emissions. Several of these technologies that have a demonstrated field performance have been slated for further study through *Federal Technology Alerts.*

Laboratory Perspective

Through laboratory testing, field testing, and theoretical analysis, ozone treatment of cooling tower water has shown to be technically valid and economically attractive in many applications. The technology works by virtue of the ability of ozone to act as a disinfectant and therefore as an alternative to traditional chemical treatment. Performance of the technology, when properly applied, has been demonstrated effective. However, like most traditional chemical treatment programs, ozone is not a cure-all. Ozone is a potential alternative to traditional chemical treatment methods. More information is needed on the effectiveness, efficiency and potential other impacts of ozone. The remaining barriers to implementation involve user acceptance and correct application. This *Technology Alert* is intended to address these concerns by reporting on the collective experience of ozone users and evaluators and by providing application guidance for Federal-sector installations.

Application

This section addresses technical aspects of applying ozone treatment technology to cooling towers. The most appropriate applications are discussed.

Application Screening

To determine whether ozone is an effective alternative for treating the water in a specific cooling tower, a technical feasibility screening study and economic (life-cycle cost) analysis should be performed. In general, cooling towers associated with chillers for commercial HVAC and light industrial process cooling are good candidates. Manufacturers claim to have treated both wooden and metal towers in sizes ranging from 60 to 10,000 tons (210 kW to 35,000 kW).

Ozone is not a corrosion inhibitor; however, the higher concentration ratios resulting from the reduced blowdown volumes raise the pH of the recirculating water, which helps protect the system from corrosion. This same pH condition will promote the precipitation of silicates and calcium carbonate if sufficient pretreatment of make-up water is not provided. Lower pH will remove the scale but will also increase the corrosion rate from the ozone. For this reason, make-up water must be of sufficient quality to avoid these problems.

The strong oxidation potential of ozone is what makes it most attractive for use as a biocide in water systems. However, this same property also makes it difficult to use ozone when there is a large chemical oxygen demand (COD) present (this will consume available ozone) in the water or if local air conditions bring in large quantities of organics to the tower. The latter condition is the reason it is not possible to implement ozone water treatment in towers within chemical plants or at oil refineries. In addition, ozone is corrosive to some materials such as rubber fittings, gaskets, and certain kinds of metals and alloys. If these materials are present in a cooling tower, they should be replaced before ozone system installation if it is practical and economical to do so.

Once ozone is in the liquid phase, it will last only a short period of time; thus, maintaining an ozone residual for more than approximately 10 minutes can be difficult. This limits the application of ozonation in large cooling towers. In large towers with 100,000 or more gallons, multiple injection points may be necessary.

Make-up water that is high in mineral content or dissolved solids may not be conducive to effective treatment; testing should take place before a system is installed and on a periodic basis during operation. A side-stream filter may be required on cooling towers operating with make-up water quality in excess of 150 ppm calcium hardness. In cases where hardness is in excess of 500 ppm as $CaCO_3$, or sulfates >100 ppm, ozone can be eliminated as a viable cooling tower water treatment. A "Cooling Tower Worksheet" is provided in Appendix A and can be used to characterize the quality of make-up water.

The U.S. Occupation Safety and Health Administration (OSHA) has established an ozone exposure limit of 0.1 ppm in air over an 8-hour shift. This could be a problem if the cooling towers are located on the ground level and are excessively treated with ozone so that the tower is operating as an ozone gas stripper (gives off ozone into the air).

Ozone produces oxidation by-products. There are several secondary products that must be accounted for in the set-up of cooling tower ozonation. Both iron and manganese will be oxidized by the ozone to form insoluble particulates that collect in basins, on screens, or in any scale that is forming. Excessive amounts of either of these two chemicals in the make-up water will require pretreatment. In addition, organic compounds that may either be in the make-up water or introduced through the atmosphere will react with ozone to form ketones, aldehydes, and amines. If bromide is present, ozone can convert bromide to hypobromous acid and hypobromite ion. These two species are known biocides and would be considered helpful in controlling biofilms but potentially detrimental in the discharge of blow down. Excessive ozone can further oxidize the hypobromite ion to bromate, reducing the effectiveness of these components as biocides.

What to Avoid

Ozone treatment failures are usually related to an inadequate quantity of applied/dissolved ozone which can be caused by excessive organic material in the water or high operating temperature. Therefore, ozone treatment should be avoided in the following situations:

- high organic loading from air, water, or industrial processes that would require a high COD (the ozone will oxidize the organics and insufficient residual may remain for the water treatment)
- water temperatures that exceed 110°F (43.3°C) (high temperatures decrease ozone residence time and reduce overall effectiveness of the ozone treatment)
- make-up water is hard (>500 mg/L as $CaCO_3$) or dirty make-up water (softening and/or prefiltering make-up water is sometimes recommended)
- long piping systems which may require long residence time to get complete ozone coverage (insufficient ozone residence time may result in incomplete coverage)

Water temperature is critical to the success or failure of a system. Above 110°F (43.3°C) the solubility of ozone is effectively zero for all concentrations of ozone in the feed gas. Even at 104°F (40°C) the solubility is very small (<3 mg/L). Although some operational data suggest that ozone may be used at temperatures of up to 135°F (57.2°C), most sources agree that ozone works best in bulk water temperatures under 104°F (40°C), preferably even below 100°F (37.7°C). Many comfort cooling systems commonly operate at between 85°F and 95°F (29.4°C and 35.0°C). As temperatures rise, the ozone will dissipate too fast and not dissolve into the water. This is one reason ozone is not appropriate for cooling tower systems such as nuclear and fossil generating plants and absorption refrigerant plants, where temperatures are generally high.

Problems can and do occur in the field. The following precautions are not always covered in manufacturers' instructions but are recommended to be taken during installation:

- Preparation of the inlet air is very important for the efficient operation of an ozone unit as well as for the longevity of the unit. The preparation of the gas includes removal of dust (particle sizes >1µm), moisture (dewpoint <-76° F (-60°C)="99.98%" moisture removed), and oil. This requires that the pretreatment system be checked periodically by properly trained personnel and that the appropriate monitoring equipment for the pretreatment process is installed.
- Make-up water should be free from noticeable sediment, mud, and discoloration and should not have extremely high levels of sulfates (<100 ppm) or hardness (<500 ppm as $CaCO_3$). These values may be determined by having the water tested by a qualified lab.
- Material in the ozone-treated system should be compatible with ozone. The ozone distribution line from the generator to the gas/water contactor carries the highest concentration (1 to 4% by weight of ozone); therefore, the line material should be constructed of stainless steel or PVC.
- For efficient operation, the ozone generator should be located in an air-conditioned area. Excessive heat (greater than 90°F) could damage the system or reduce generation capacity.
- The actual capacity of the ozone generator should be certified by the manufacturer and checked yearly by the ozone vendor or a qualified maintenance contractor.
- Corrosion coupons for copper and steel should be placed in the system and checked at least every 6 months.

Normally the cooling tower manufacturer or vendor furnishes operating and maintenance manuals and training. Manufacturers' instructions should continue to be followed after the system is installed.

Quantitative Measurements

Ozone concentration in the water can be measured. The measurement of ozone concentration has been a source of some debate in the past. Two measurement methods are in use today that are fairly well accepted. These are Absorption of UV light as determined by the Beer-Lambert Absorption Law (OREC) and the Indigo method 8311 of HACH Company. The UV absorption method is useful for on-line monitoring of the ozone concentrations in systems for cooling tower water treatment.

A useful indicator of scaling is proposed by Pryor and Buffum, called Practical Ozone Scaling Index (POSI). This index is a correlation for traditional scaling indices for use in ozone treated systems. Tierney, Feeney, and Mott propose examining the solubility based on activity coefficients as a function of ionic strength using the DeBye-Huckel equation. This latter approach is a direct assessment of scaling under super saturated conditions.

Equipment Integration

The ozone systems for cooling tower application on the market today are typically modular and fully self-contained systems with an independent circulation system for side stream installation. Ozone generators operate from line voltage of 120 volts single-phase, 230 volts single- and three-phase, and 440 volts single- and three-phase, at 60 Hz. The higher the output, the more desirable it is to operate from a higher voltage and multi-phase source. Electric service breakers are system-mounted for single-point electrical connection. Units can arrive completely wired and piped, with all components mounted on structural steel skids.

The necessary piping (usually PVC) and circulation pumps must be provided to connect the system to the cooling tower water sump. Sometimes, filters must be installed to capture mineral deposits that will occur from the ozone treatment. Installation can typically be completed in one day provided the appropriate electrical service is in place.

Monitoring and control packages can include integral alarms. Also, interlocking features are available so that remote fans, blowers, pumps, solenoid valves, etc. will be activated upon start up of the ozone generator and vice versa.

Different ozone systems have different dimensions or "footprints." A system designed to treat a 1,000-ton (3,500-kW) tower may have width-height-depth system dimensions of 37 x 32 x 55 inches (0.94 x 0.81 x 1.4 meters) to 90 x 60 x 30 inches (2.3 x 1.5 x 0.76 meters). To maximize the use of ozone during its short half-life, the ozone-containing water should be returned to the sump of the cooling tower as close as possible to the suction side of the circulation pumps, to ensure that the maximum amount of oxidant is circulated through the piping and heat exchangers and that some ozone remains to be returned to the top of the cooling tower.

Maintenance

As with any technology, it is important to perform routine maintenance in order to preserve overall efficiency and effectiveness, as well as to extend equipment life. Preventive maintenance recommendations are listed in Table 1.

Table 1. Recommended Preventive Maintenance

Frequency	Description
Three months	Check/change filters
Six months	Change brushes on powerstat control General cleaning Remove dust from transformers Check cooling water system Check low pressure safety cut-out switch

Annually	Check dielectrics Clean high voltage bushings Change humidity sensor Check relief valves for proper operation General inspection for water leaks
Other	Check air dryer pre- and post-filter as specified by air dryer manufacturer Change air dryer desiccant (if used) every three years Check air compressor system every six months

Warranties

Ozone technology appears to be a reliable method for cooling tower water treatment. As with any water treatment process, there are reported successes and failures. As with most equipment, warranties vary between manufacturers. Although a full comparison of warranty information cannot be provided in this *Technology Alert*, one manufacturer warrants the electrodes in the ozone generator for three years.

The reader should inquire into the ozone equipment warranty directly from the ozone equipment manufacturer or sales representative. In addition, the reader should inquire into the impact on the chiller and cooling tower equipment warranties directly from the providers of the chillers and cooling towers. Some ozone technology providers disclaim any warranty with regard to the use of the ozone equipment. The actual terms of the warranty are usually set forth in the specification submittal or documents of sale. The reader is encouraged to investigate the equipment warranties.

Costs

Costs for a typical ozone system capable of treating a 1,000-ton (3,500-kW) cooling tower are estimated to range from $25,000 to $70,000, depending upon manufacturer and actual system size. $36/ton of cooling may be used to provide a rough cost estimate for an ozone system. The ozone systems are sized according to need and range from 10 gram/hour to 3,700 gram/hour with corresponding prices ranging from $10,000 to $300,000. The wide range in cost is a result of the fact that the size, and subsequently the cost, of the system depends heavily upon the operating temperature and operating environment of the tower.

Utility Incentives and Support

Although no utilities currently offer rebates for ozonation, a number have sponsored seminars and disseminated information. Some have sponsored field tests and comprehensive studies. The reader is urged to contact your local utility to see if any energy savings rebates are available.

Texas Utilities (TU) has worked with one company since spring of 1994 and has completed four ozone installations for TU customers. Southern California Edison has studied installations and offers information to its customers. Pacific Gas & Electric evaluated a test installation over a two-year period and concluded that ozone was "superior to the current, conventional, multi-chemical treatment program." Georgia Power, Alabama Power, and the TVA all sponsored onsite seminars on cooling tower ozonation for their customers in 1994.

Technology Performance

A large number of case studies have been reported by manufacturers and others. Observations of field performance, obtained from Federal- and private-sector analysts and users, are summarized below.

Pacific Gas and Electric reported effective use of ozone as a biocide following a 2-year study of treatment of mechanical draft counter flow water cooling towers at a large gas production utility site.

An Electric Power Research Institute (EPRI) case study focuses on the Digital Equipment Corporation offices in Littleton, Massachusetts, a 500,000 square-foot complex. The ozonation system was commissioned in 1989. Digital engineers found ozonation to be economically and environmentally superior to previous chemical treatments. In addition to the biocidal effect, ozonation reduced blow down and eliminated the need for employees to handle chemicals. Tests over 2.5 years showed no scale formation; corrosion rates were within industry standards and equipment manufacturer recommendations. Operating costs were reduced by almost $90,000 per year, and the payback period for capital investment was only about 2 years.

In 1984-85, NASA performed an experiment in which a 600-ton cooling tower was retrofitted with an "Ozone-Air HF-90" solid-state ozone generator, which used 60% less electricity to make a pound of ozone than a conventional transformer/glass-electrode generator (6.1 vs. 15.3 kWh/lb ozone). The generator cost a total of $16,057 for a 2-cfm air compressor, air dryer, and ozone generator. Its use decreased the cooling tower's bacterial count by four orders-of-magnitude and turbidity by eightfold. Scale accumulations on the tower loosened and fell off. The effect on chiller energy consumption was not measured, but the condensers were found to be clean and looking as though they were newly retubed. Negative impacts included ozone attack on galvanized steel, copper, and nylon fittings; these were eventually replaced with PVC and stainless steel.

Case Study I

This case study examines a system of four ceramic-filled concrete cooling towers with a capacity of 2,500 tons (8,750 kW) each. The towers reject heat from the air-conditioning system that provides temperature and humidity control for Space Shuttle processing in the Vehicle Assembly Building (VAB) at NASA's Kennedy Space Center (KSC), Florida.

Facility Description

The cooling towers that provide service to the VAB are located in the Utility Annex (central plant) at KSC. The make-up water is purchased from a Privately Owned Treatment Works (POTW) at a cost of $1.18/1,000 gallons ($0.31/1,000 liters) and blow down was discharged to local surface waters. Chemical treatment for the cooling tower was $10.18/ton per year ($2.91/kW) and consisted of two phase scale and corrosion inhibitors and alternating biocide application. In 1990, the Florida Administrative Code (FAC) 17-302, Surface Water Quality Standards, introduced stricter environmental regulations that made the blow down water unable to meet regulatory criteria for discharge to the local surface waters. Hence, ozone treatment was installed in February 1994 in an attempt to reduce the amount of blow down being discharged.

Existing Technology Description

The four cooling towers have a total capacity of 10,000 tons (35,000 kW) and contain a total of 204,000 gallons (772,000 liters) of cooling water. The towers had an average make-up water volumetric rate of 146,000 gal/day (553,000 liters/day). Blow down averaged 67,200 gal/day (254,500 liters/day) with the rest being a combination of drift and evaporation. The towers reportedly were operated with a concentration ratio in the range of 4 to 7. Cooling water is circulated at 7,500 gal/min (28,400 liters/minute) through each tower. The tower water temperature drops from 110°F (43.3°C) to 90°F (32.2°C).

Ozone Equipment Selection

Ozone vendors have well-developed specifications for the implementation of ozone-producing equipment. These criteria consider all aspects of the system. Many factors must go into the decision to use ozone as a cooling tower water treatment. Among these factors are the operating environment, operating temperature, material resistance to ozone, and condition of the make-up water. However, it is important to have an estimate of the size and cost of an ozone system before contacting a vendor.

The size, cost, and operating conditions of the existing system should be obtained so that a comparison can be made with using ozone. If this information is not available, the inputs needed may be estimated in the Cooling Tower Worksheet. It is necessary to know the nominal rating of the cooling tower(s) under examination. Cooling tower capacity is usually expressed in terms of tons. Once the tower capacity is obtained, the system can be sized using the equations identified in the Cooling Tower Worksheet, as shown in Figure 4.

Modified Cooling Tower Analysis Worksheet

Existing chemical treatment system:

(A) circulation rate = 3 * 10,000 = 30,000 gal/min
actual circulation rate reported to be 30,000 gal/min (4 towers @ 7,500 gal/min each)
note: default is 3x tower capacity

(B) blowdown water = 24,528,000 gal/yr (metered)

(C) make-up water = 53,290,000 gal/yr (metered)

(D) concentration ratio = 53,290,000 / 24,528,000 = 2.17

(E) evaporation and drift water = 53,290,000 - 24,528,000 = 28,762,000 gal/yr

(F) operating load factor = 0.21 (estimate)
note: default is between 0.25 to 0.50, if actual is unknown

(G) average blowdown rate = 24,528,000 / (8,760 * 60 * 0.21) = 222.2 gal/min

(H) make-up water rate = 53,290,000 / (8,760 * 60 * 0.21) = 482.8 gal/min
evaporation and drift rate = 482.8 - 222.2 = 260.6 gal/min

(I) make-up water cost = (water cost in $/gal) * C = $1.18/1,000 gal * 53,290,000 = $ 62,880 /yr
note: default $1.00/1000 gal, if actual water cost is unknown

(J) blowdown cost = $ 0.00 * 24,528,000 = $ 0 /yr
actual blowdown disposal cost is $0 because blowdown not sent to a POTW
note: default is $0.50/1000 gal, if actual disposal costs are unknown

(K) chemical treatment cost = $10.18 /ton * 10,000 tons = $101,800 /yr

(L) annual total cost = I + J + K = $ 62,880 /yr + $ 0/yr + $ 101,800 /yr = $ 164,680 /yr

Proposed ozone treatment system:

(M) new concentration ratio = 15
note: default is 15, if actual target is unknown

(N) proposed blowdown = 0.9 / (M - 1) = 0.9 / (15 - 1) = 0.0643

(O) proposed blowdown rate = N * A / 100 = 0.0643 * 30,000 / 100 = 19.3 gal/min

(P) proposed make-up water = (evaporation and drift rate + O) * (8,760 * 60 * F) = (260.6 + 19.3) * (8,760 * 60 * 0.21)
= 30,894,200 gal/yr

(Q) ozone system size (in grams per hour) = 0.023 * A = 0.023 * 30,000 = 690 g / hr
note: to convert to lb/hr divide Q by 454.

(R) proposed make-up water cost = (water cost in $/gal) * P = $1.18/1,000 gal * 30,894,200 = $ 36,455 /yr
note: default is $1.00/1000 gal, if actual cost of water is unknown

(S) proposed blowdown cost = (disposal cost in $/gal) * O * (8,760 * 60 * F) = $0.00 * 19.29 * (8,760 * 60 * 0.21)
= $ 0 /yr
note: default is $0.50/1000 gal, if actual disposal costs are unknown

(T) ozone system cost = (600 * Q) + 10,000 = (450 * 690) + 10,000 = $ 320,500
note: Use 450 instead of 600 if Q > 200 g/hr.

(U) ozone unit energy consumption = 114 * Q = 114 * 690 = 78,660 kWh/yr

(V) ozone electricity operating cost = (electricity cost in $/kWh) * U = $0.0478 * 78,660 = $ 3,760 /yr

(W) proposed ozone operating cost = R + S + V = $ 36,455 /yr + $ 0 /yr + $ 3,760 /yr = $ 40,215 /yr

Fig. 4. Case Study I Worksheet

Savings Potential

A preliminary analysis will provide estimates that will be useful in making a decision to implement ozone as a treatment for cooling tower water. The estimation of the size and cost of an ozone system can be done at several levels of detail. The highest level of estimation is based on an average installed cost of an ozone system based on the nominal tonnage of the tower. An installed cost of $10/kW ($36/ton) is typical for smaller systems. As the ozone generators get larger, the cost per ton can drop. An average chemical treatment program cost is $10/ton per year while an average ozone treatment will cost around $2/ton per year. The cost of make-up water and disposal of blow down can vary widely and should be obtained for the particular cooling tower application under consideration. In addition, local energy costs should be used for the ozone energy consumption. The estimated costs and savings for the Utility Annex cooling tower system are listed in Table 2.

Table 2. Estimated Cooling Tower System Operating Information

	Existing system	Ozone system	Difference
Operating cost	$ 164,680/yr	$ 40,215/yr	$ 124,465/yr
Ozone equipment cost	not applicable	$ 320,500	($320,500)
Annual water use	59,130,000 gal	30,894,200 gal	28,235,800 gal

Life-Cycle Cost

The estimates from the above calculations are to use a 690 gr/hr ozone generator. Annual savings are estimated to be $124,465. Using the Building Life-Cycle Cost software (BLCC 4.20-1995) available from the National Institute of Standards and Technology (NIST), the total life-cycle cost for the ozone technology is $663,850 compared to a life-cycle cost of $1,463,555 for the conventional chemical treatment program. A life cycle of 10 years was used in this analysis. The comparison report from the BLCC software is illustrated in Figure 7. The resulting net present value (NPV) is determined to be $799,705 and the savings-to-investment ratio (SIR) is 3.5. More information on Federal life-cycle costing and the BLCC software can be found in Appendix B.

NIST BLCC: COMPARATIVE ECONOMIC ANALYSIS (version 4.20-95)

BASE CASE: Chemical Tower[a]
ALTERNATIVE: Ozone Tower[b]

PRINCIPAL STUDY PARAMETERS:

ANALYSIS TYPE: Federal Analysis--Energy Conservation Projects
STUDY PERIOD: 10.00 YEARS (JAN 1995 THROUGH DEC 2004)
DISCOUNT RATE: 3.0% Real (exclusive of general inflation)
BASE CASE LCC FILE: CHEMICAL.LCC
ALTERNATIVE LCC FILE: OZONE.LCC

COMPARISON OF PRESENT-VALUE COSTS

	BASE CASE: ChemicalTower	ALTERNATIVE: Ozone Tower	SAVINGS FROM ALT.
INITIAL INVESTMENT ITEM(S):			
CASH REQUIREMENTS AS OF SERVICE DATE	$0	$320,500	-$320,500
SUBTOTAL	$0	$320,500	-$320,500
FUTURE COST ITEMS:			
ANNUAL AND NON-AN. RECURRING COSTS	$868,374	$0	-$868,374
ENERGY-RELATED COSTS	$0	$32,380	-$32,380
WATER COSTS	$595,181	$310,970	$284,211
SUBTOTAL	$1,463,555	$343,350	$1,120,205
TOTAL P.V. LIFE-CYCLE COST	$1,463,555	$663,850	$799,705

NET SAVINGS FROM ALTERNATIVE OzoneTower COMPARED TO ALT. ChemicalTower

Net Savings = P.V. of non-investment savings $1,120,205
- Increased total investment $320,500

Net Savings: $799,705

SAVINGS-TO-INVESTMENT RATIO (SIR)
FOR ALTERNATIVE Ozone Tower COMPARED TO ALTERNATIVE Chemical Tower

$$SIR = \frac{\text{P.V. of non-investment savings}}{\text{Increased total investment}} = 3.50$$

ADJUSTED INTERNAL RATE OF RETURN (AIRR)
FOR ALTERNATIVE Ozone Tower COMPARED TO ALTERNATIVE Chemical Tower
(Reinvestment rate = 3.00%; Study period = 10 years)

AIRR = 16.73%

ESTIMATED YEARS TO PAYBACK
Simple Payback occurs in year 3
Discounted Payback occurs in year 3

ENERGY SAVINGS SUMMARY

Energy type	Units	Annual Consumption Base Case	Annual Consumption Alternative	Annual Consumption Savings	Life-Cycle Savings
Electricity	kWh	0	78,660	-78,660	-786,600

(a) File name for cooling tower using conventional chemical water treatment (base case)
(b) File name for cooling tower using ozone water treatment technology

Fig. 5. Building Life-Cycle Cost (BLCC)

Implementation and Post-Implementation Experience

The ozone system installed at the Utility Annex has a generation capacity of 600 gr/hr. For comparative purposes, the actual costs and savings reported by Tierney and Mott are identified in Table 3. The overall savings was determined to be $100,012/year. Experience at the Utility Annex cooling towers has shown that ozone treatment is indeed a viable water treatment method for cooling towers. The idea that zero blow down can be practiced is not feasible, since the calcium levels will eventually get too high and scale will form. At 60 to 80 cycles, the cooling towers were 60% plugged with scale in 8 months. In addition, the ozone injection circuit was plagued by the same problem and was difficult to keep on line. This forced the operators to reduce the concentration cycles between 10 and 20. Research indicated that they could increase the concentration cycles between 30 and 40, which is where they are now.

Table 3. Reported[(a)] Cooling Tower Operating Information

	Existing system	**Ozone system**
Operating cost	$ 161,484/yr	$ 61,472/yr
Ozone equipment cost	not applicable	$ 330,000
Annual water use	53,290,000 gal	35,690,000 gal
(a) Reported from telephone interview with site personnel.		

The ozone generator failed several times due to excessive heat but was covered by the manufacturer's warranty. To remedy the failure conditions of the ozone unit, an air-conditioned enclosure was built to remove some of the cooling load on the ozone generator's cooling system. This points out the need to have the cooling system for the ozone generator serviced regularly to reduce failures in the unit and to consider the cost of enclosing and cooling the unit if it must operate in a high temperature environment.

Ozone injection systems are susceptible to scale build-up due to the dry ozone/air stream coming into contact with the mineral-saturated cooling tower water. This problem was solved by injecting potable water (which is not mineral-saturated) at the site of ozone injection.

Overall, the results are good. The reduction in blow down, make-up water, and chemical costs usually will provide a simple payback time of less than six years.

Case Study II

This case study concerns a system of two cooling towers with a capacity of 300 tons each, located at the Lockheed Martin Electronics and Missiles Ocala Operation in Ocala, Florida. Data were taken from a paper written and presented at the DOE Pollution Prevention Conference XI in Knoxville, Tennessee, on May 16, 1995 (See "Who Is Using the Technology" for a contact at Lockheed Martin).

The Lockheed Martin Electronics and Missiles Ocala Operation is responsible for the production of electronic assemblies, printed circuit boards, and wiring harnesses for space exploration, defense weapon systems, and defense communication systems. The cooling towers support a variety of test and production equipment and also support secondary cooling of HVAC systems.

The cooling tower system consists of two conventional Marley counter flow cooling towers with an operating capacity of 500 gallons each. The towers operate with an influent water temperature of 85°F (29.4°C) and an effluent temperature of approximately 75°F (23.8°C), for an overall temperature drop of 10°F (5.6°C). The facility was not connected to a public works wastewater treatment facility, so the blow down water had to be transported offsite for disposal, at an annual cost of $45,360.

The cooling towers had an annual make-up water volume of 2.482 million gallons. Since the installation was not connected to an outside water source, the source of make-up water was treated wastewater recycled from the manufacturing process. This make-up water had a total organic carbon (TOC) content that was greater than 1500 ppm. This high TOC concentration resulted in a large chemical demand in treating the cooling tower water, which was reflected in the overall chemical treatment costs. The water was soft (~=50 ppm as $CaCO_3$) and contained ferrous sulfate from the manufacturing process. Poor system control resulted in either excessive chemical use or insufficient chemical feed, with subsequent scale formation requiring acid cleaning. The tower required acid cleans several times a year and the chiller condensers were cleaned at least twice during the summer months due to biofilm growth that resulted in excessive pressure head.

The existing multi-chemical treatment program consisted of the application of chlorine gas, additional biocides, and corrosion inhibitors. The total annual chemical costs were $24,733.

The savings data identified in Table 4 were generated by personnel in charge of system operation. Significant savings were achieved in all elements of the process: labor, energy, chemical, and blow down disposal.

Table 4. Operating Cost Comparison for Cooling Water System Per Year

Item	Chemical Treatment	Ozone Treatment
Electrical operation	$0	$2,592
Chemicals	$18,613	$0
Labor	$9,360	$2,808
Blowdown hauling	$45,360	$4,536
Chlorine gas	$6,120	$0
Power consumption	$118,715	$47,479
Total cost/year	$198,168	$57,415

Savings with ozone treatment were $140,753/year with an NPV of $1,072,235 and an SIR of 31.9.

In this situation, prior to the installation of the ozone system, the costs and maintenance were high enough to cause the facility to examine alternative methods for cooling tower water treatment. The result was a decision to use ozone for the treatment of the water. A proposal from REZ-TEK International, Inc. was obtained in 1993 for the installation. In February 1994, a REZ-TEK model S-1230 was installed and put into service. The model S-1230 produces 0-30 grams of ozone per hour and sold for around $35,000. The ozone system came completely self-contained with a foot print of 37 inches by 30 inches and a height of 55 inches. The appropriate electric service was already in place, so the installation of the unit took one day. It should be noted that the time and cost of installation will increase if the appropriate electrical service is not available.

During initial start-up of the system, a significant amount of suspended particles were observed. This was from the precipitation of the minerals in the water and was an expected phenomenon. In this application, the suspended solids were removed by application of hydrogen peroxide as make-up water pretreatment. Addition of ferrous sulfate was also eliminated from the make-up water, and the sump water was filtered.

The bacterial count was reduced three orders-of-magnitude, from one million to one thousand colony-forming units (CFUs), and blowdown waste was reduced 90%. The operator reported that no chemicals had been added to the cooling tower one year after the ozone system was installed.

Labor savings were reported qualitatively: "Maintenance operator was enabled to alternate one chiller and remove waste heat from air conditioning and test chambers. System has allowed the maintenance operator time to focus on the other facility issues."

An important aspect of this type of savings is that it will free up maintenance staff to address other operation and maintenance issues at the facility.

Corrosion tests indicated that copper in the tower neither corroded nor pitted, while iron showed 2.0 mils per year of corrosion and 0.37 mils per year of pitting. It was reported that the corrosion effect of ozone was 50% of that of chlorine treatment.

The findings of the case study were very positive one year after installation and start-up.

The Technology in Perspective

Much excitement has been generated around this technology. Manufacturers and vendors see a huge market; cooling tower operators see the potential costs savings, environmental benefits, and reductions in maintenance and health hazards. As a result, many players have appeared in the field along with a variety of products, services, and performance claims.

With each installation, more is learned about actual performance, cost, and benefits. There have been reports of success and of failure. Manufacturers indicate that many of the failures were due to poor design or inferior quality ozone-generating equipment. Sometimes the application of ozone was inappropriate due to the make-up water condition or the tower operating conditions. In these situations, a traditional chemical treatment program will be more effective.

There are many reasons to consider ozone: when chemical costs are high or chemical management is burdensome, when chemical water treatment is not effective, when water and sewer charges are high or increasing, or when local regulations require blowdown to be treated before discharge to surface waters.

Potential users should carefully review their current and historic costs related to cooling tower water treatment and the performance of their associated cooling equipment. The guidance provided in this *Technology Alert* should help indicate whether it would be worthwhile to consider the technology.

Who Is Using the Technology

The list below is a partial list of Federal-sector contacts, agencies, and locations that already have the new technology installed and operating. Many of the listed Federal energy managers are knowledgeable about ozone for cooling tower water treatment. The reader is invited to ask questions and learn more about the new technology.

Kennedy Space Center (EG&G)
Kennedy Space Center, FL
Dan Tierney (407) 867-1190

Lewisburg Penitentiary
Lewisburg PA
Lou Bremenen (717) 523-1251 x418
Lockheed-Martin
Ocala, FL
Arvind Patel (904) 687-5683
Martin-Marietta
Oak Ridge, TN
Terry Copeland (615) 574-1550
McDonnell-Douglas Space System
Kennedy Space Center, FL
Jose Rodriguez (407) 867-5141
NASA Houston
Houston, TX
Mark Watts (713) 666-2828
United States Post Office
Manchester, NH
Ron Bruzenski (603) 644-4071

For Further Information

Ozone Treatment for Cooling Towers FTA - Appendix A

Ozone Treatment for Cooling Towers FTA - Appendix B

The documents listed below were used in the preparation of this *Technology Alert* and may be of further use to anyone considering application of cooling tower ozone treatment. A list of pertinent associations and organizations is also provided.

User and third party field and lab test reports and other technical publications:

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Contacts

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Produced for the U.S. Department of Energy by the Pacific Northwest National Laboratory

December 1995